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PHASE III DEVELOPMENT OF THE CALSPAN RSV AIR BELT RESTRAINT SYSTEM

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FOREWORD

This report presents the results of testing and analysis performed to develop an air belt restraint system for the Research Safety Vehicle (RSV). During the second phase of the RSV program, an air belt concept was developed and tested utilizing idealized components without regard to their producibility. The objective during the present third phase program was to replace those Phase II components with producible hardware without significantly compromising the demonstrated Phase II performance levels. Acceptability required passive operation of the system. Details of the component and sled tests performed in arriving at a producible configuration are included.

This report is submitted as part of a program of research conducted by Calspan Corporation for the National Highway Traffic Safety Administration under Contract No. DOT-HS-7-01551. The Contract Technical Manager for the program is Franklin G. Richardson, DOT/NHTSA.

The opinions and findings expressed in this publication are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

This report has been reviewed and is approved by

G. J. Fabian
Program Manager

1.0 INTRODUCTION

This report summarizes the effort associated with the Phase III development of the front seat air belt restraint system for the Calspan RSV. During Phase II of the program, an air belt design was conceptualized and tested using idealized, non-production components. The objective of the Phase III program was to develop a producible system without significantly compromising the performance level demonstrated in Phase II. Optimizing performance for the 50th percentile male was the underlying goal of the Phase II as well as the Phase III work. Demonstrations with other size dummies, most notably the 5th percentile female and 95th percentile male dummies, were of secondary importance. The scope of effort performed during Phase III was divided into three distinct tasks.

The first task was a critical review of the Phase II system. Static and dynamic tests were conducted with alternative consumer acceptable components that could be used to replace the idealized hardware used in Phase II. The components selected were then integrated into the air belt design. The output from this first task was a preliminary design for the Phase III air belt system using production hardware. At this point, developmental sled testing, the second task, began. Twenty-seven sled runs were performed leading to a final system design.

Lastly, a series of twenty-five validation sled tests was conducted to determine system performance sensitivity. Variables examined included occupant size, sled speed, lap belt use, seat position and sled angle. Emphasis for both the developmental and validation tests was directed toward demonstrating performance with the 50th percentile male size occupant dummy in both the driver and passenger seating positions.

The format of this report follows the progression of effort delineated in the preceeding paragraphs. Prior to discussing Phase III activities, a review of the Phase II design is presented (Section 2). Component, developmental, and validation testing results are summarized in Sections 3, 4 and 5. Conclusions and recommendations are given in Section 6.

2.0 RECAPITULATION OF THE PHASE II AIR BELT RESTRAINT SYSTEM

Conventional, three-point-restraint belt systems have a number of inherent deficiencies that manifest themselves at increasingly higher vehicle impact speeds.

- Head restraint is lacking.
- Belt forces increase to the point that the chest deceleration injury criterion may be exceeded.
- Because of the relatively small surface contact area of a conventional belt, load distribution on the torso is poor from a biomechanical standpoint.
- Belt slack and spooloff from the retractor result in a significant loss of ridedown.

The Phase II final design concept for the RSV air belt restraint is illustrated in Figure 1. This system was designed to alleviate the problems associated with conventional belts. The inflatable portion of the air belt distributes the loads on the chest over a large surface area, removes belt slack by the reduction in length (which is a consequence of inflation) and provides some head support.

The web clamp, located between the roof rail retractor and the inflatable portion of the air belt, locks up under low level belt loads and prohibits webbing from spooling off the retractor during impact. This feature improves ridedown and, when coupled with the air belt, allows the latter to act as a pretensioning device which also aids ridedown.

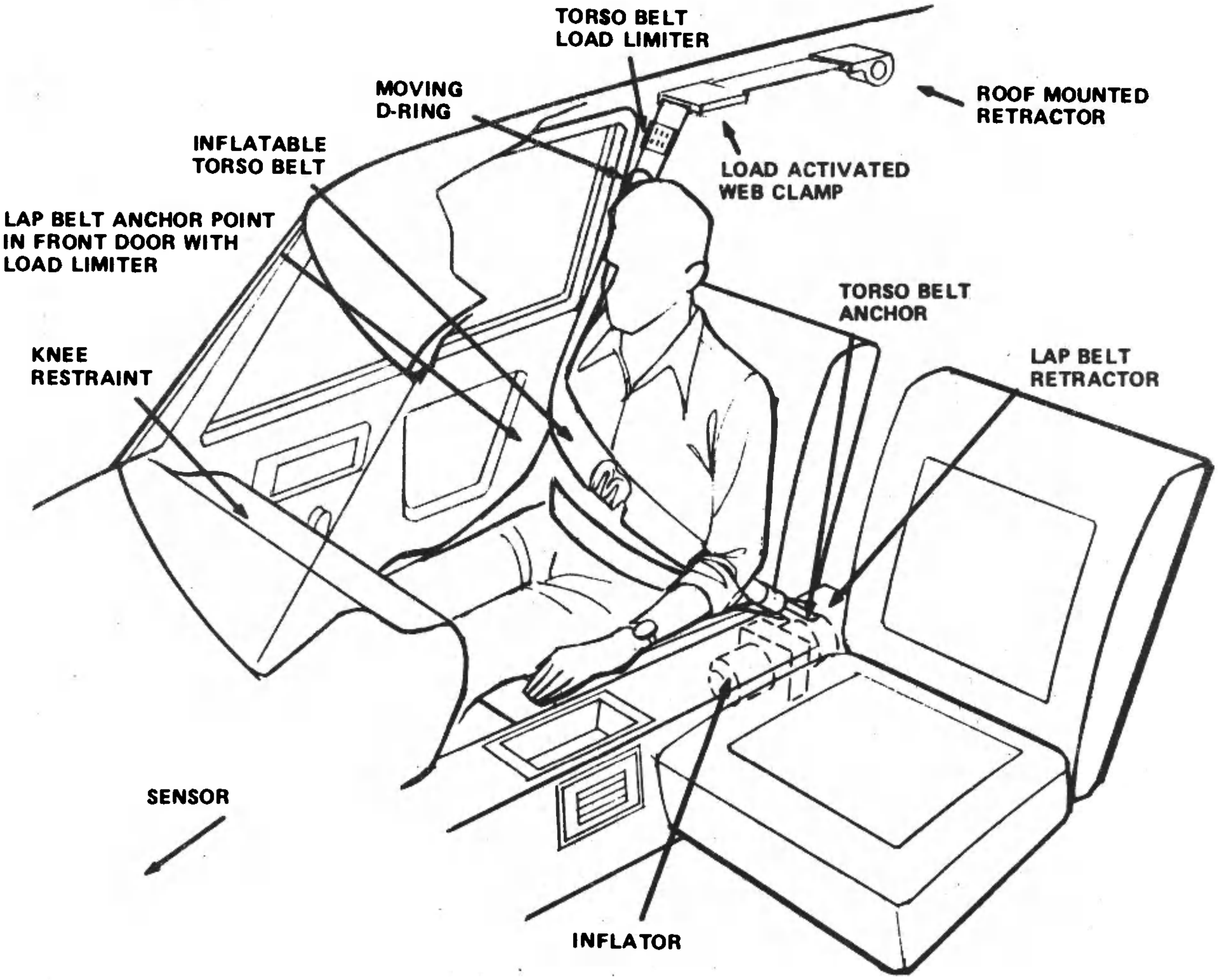
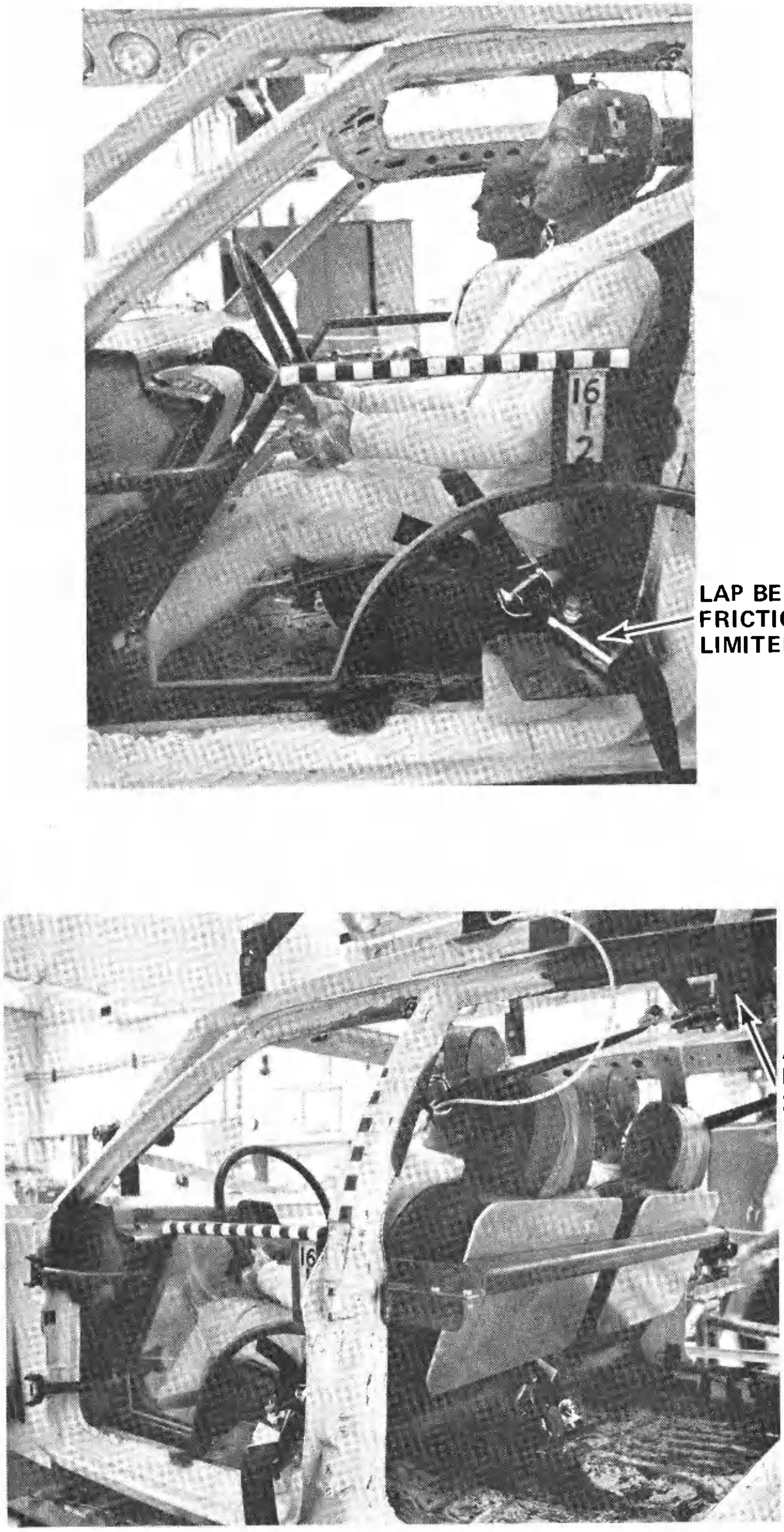


Figure 1 FRONT SEAT OCCUPANT PROTECTION SYSTEM – PHASE II DESIGN CONCEPT

Finally, a load limiter, positioned between the web clamp and inflatable portion of the belt, controls the forces being applied to the occupant's chest. Integration of all these components results in a system design that can elevate protection up to the 45 to 50 mph impact speed regime.

It should be reiterated that Figure I represents the Phase II final design concept. Actual air belt restraint testing conducted during that time period utilized idealized components that were not suitable for integration into a producible, consumer acceptable design. Specifically,

- The inflation source was stored gas from a pressurized gas cylinder. A replacement pyrotechnic gas generator device was required.
- Air belt force limiting at 2000 pounds was achieved mechanically by pulling a steel rod through constrained offset rollers. A friction clamp was used as the energy dissipating mechanism for the lap belt (500 pounds limiting level). Both of these force limiters were heavy and bulky, and neither could be incorporated into a passive restraint (see Figure 2).
- The web clamp did not exist and was simulated by testing with an inch of webbing on the retractor spool instead of 24 inches (Phase II requirement).
- The "semi-passive" lap belt, which was required to obtain acceptable performance in some cases, was simply not passive and hence could not be considered part of the basic passive design.



LAP BELT
FRICTION LOAD
LIMITER

AIR BELT
METAL BENDING
2000 LB LOAD
LIMITER

Figure 2 THIRD SERIES PHASE II SLED TEST CONFIGURATION

Thus, to restate, the major goal in the Phase III restraint system effort was to replace the above components with producible hardware which would be capable of providing the restraint characteristics required. Note that nearly every component of the Phase II system, i.e., inflator, load limiters and functional web clamp as well as some additional components did not exist in a producible design at the end of Phase II.

The following section details the component tests that were performed to arrive at the producible system examined in the Phase III sled testing.

3.0 TESTING OF AIR BELT RESTRAINT SYSTEM COMPONENTS

Two inflators of different manufacturer, two load limiter designs of different manufacturer, and a web clamp were examined via static and dynamic testing. Concurrently, these alternative components were mocked up in a base vehicle, the Simca 1307, to assess potential geometry problems associated with layout, i.e. space, and with passive operation of the restraint system. At the conclusion of these component tests, a preliminary integrated design and geometry were defined for developmental sled testing.

3.1 Web Clamp Tests

As mentioned previously, the function of a web clamp is to eliminate the low force-level webbing extension from the retractors which would normally occur during the crash event and thus improve the ridedown afforded by the restraint system. The magnitude of this retractor spooloff problem is a function of webbing length on the retractor, spool diameter, webbing characteristics, and the occupant loading geometry. For the RSV restraint system in particular, an average total spooloff of three inches was observed for 18 inches of belt on the retractor spool.

A webbing locking device under development by Allied Chemical Automotive Division was examined for use with the RSV air belt system. This unit, pictured in Figure 3, remains open permitting belt travel until a belt force due to lock-up of the inertia retractor exceeds the bias spring constant (≈ ten pounds). The clamping surfaces then close and lock the belt in place. The web clamp effectively becomes the anchor point and transmits no load to the retractor.

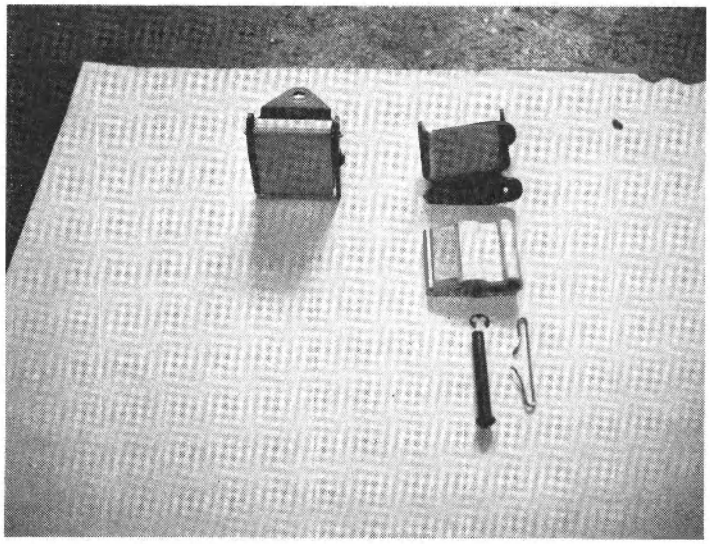


Figure 3 WEB CLAMP

Both static tensile and dynamic drop tests were performed with web clamps supplied by Allied. The dynamic drop test set-up is illustrated in Figure 4. Belt slippage through the web clamp was monitored as a function of the angle between the web clamp surfaces and the applied belt load. Results for the dynamic tests are presented in Table 1. The tabulated data indicate acceptable and consistent web clamp performance for belt-to-clamping surface angles (θ) of 45° to 90°. The belt excursions through the web clamp were limited to 3/4 of an inch or less, and negligible loads were transmitted through the web clamp to the retractor.

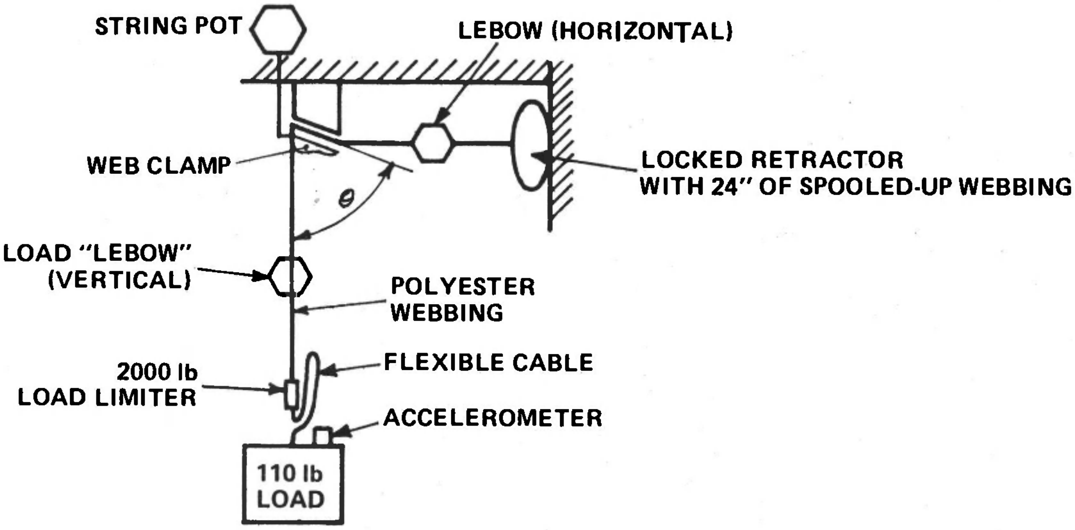


Figure 4 DYNAMIC DROP TEST SET-UP FOR WEB CLAMP EVALUATION

The results for belt to clamp surface angles of 105° and 120° were unacceptable. The 105° angle configuration was the borderline case. Substantial belt slippage occurred and significant tensile loads were transmitted through the web clamp at or above this angle.

Integration of the web clamp into the air belt design was obviously affected by these results. In order to assure that the angle between the clamping surfaces and the applied belt load, θ, did not exceed 90° during the crash event, the retractor was turned around to face rearward and the web clamp was located aft of the retractor (see Figure 5). With this geometry, θ, was limited to a maximum of approximately 30°. Although no component tests were performed with θ less than 45°, reduction in angle was not considered to be a problem.

Table 1
DYNAMIC WEB CLAMP TESTS

BELT ANGLE θ	TEST NO.	VERT. BELT LOAD		HORIZ. BELT LOAD		BELT MOTION (in.)		COMMENTS
		PEAK	EST. AVG. PEAK LEVEL	PEAK	EST. AVG. PEAK LEVEL	MAX.	PERM.	
45°	10	2050	2000	*		.76	.20	
60°	8	2040	1960	*		.64	.16	
60°	9	2000	1940	*		.68	.08	
75°	6	2020	1900	*		.58	.16	
75°	7	2020	1900	*		.52	.08	
90°	1	2080	2000	*		.62	.12	
90°	2	2150	2050	*		.60	.08	
105°	3	2080	–	26	22	.58	.20	
105°	4	1960	1500	480	450	29.2	–	ERRATIC BELT LOAD, BELT SLIPPAGE
105°	5	2175	2050	22	20	.70	?	
120°	11	1780	1400	640	400	∼1.4	–	MAX. BELT MOTION ERRATIC, PROBABLE STRING POT SLIPPAGE, ESTIMATED SLIP ≈ 3" FROM BELT MARKINGS
120°	12	2200	1900	760	550	∼5.3	–	

*WITHIN INSTRUMENT NOISE LEVEL, ESTIMATED LESS THAN 10 LBS.

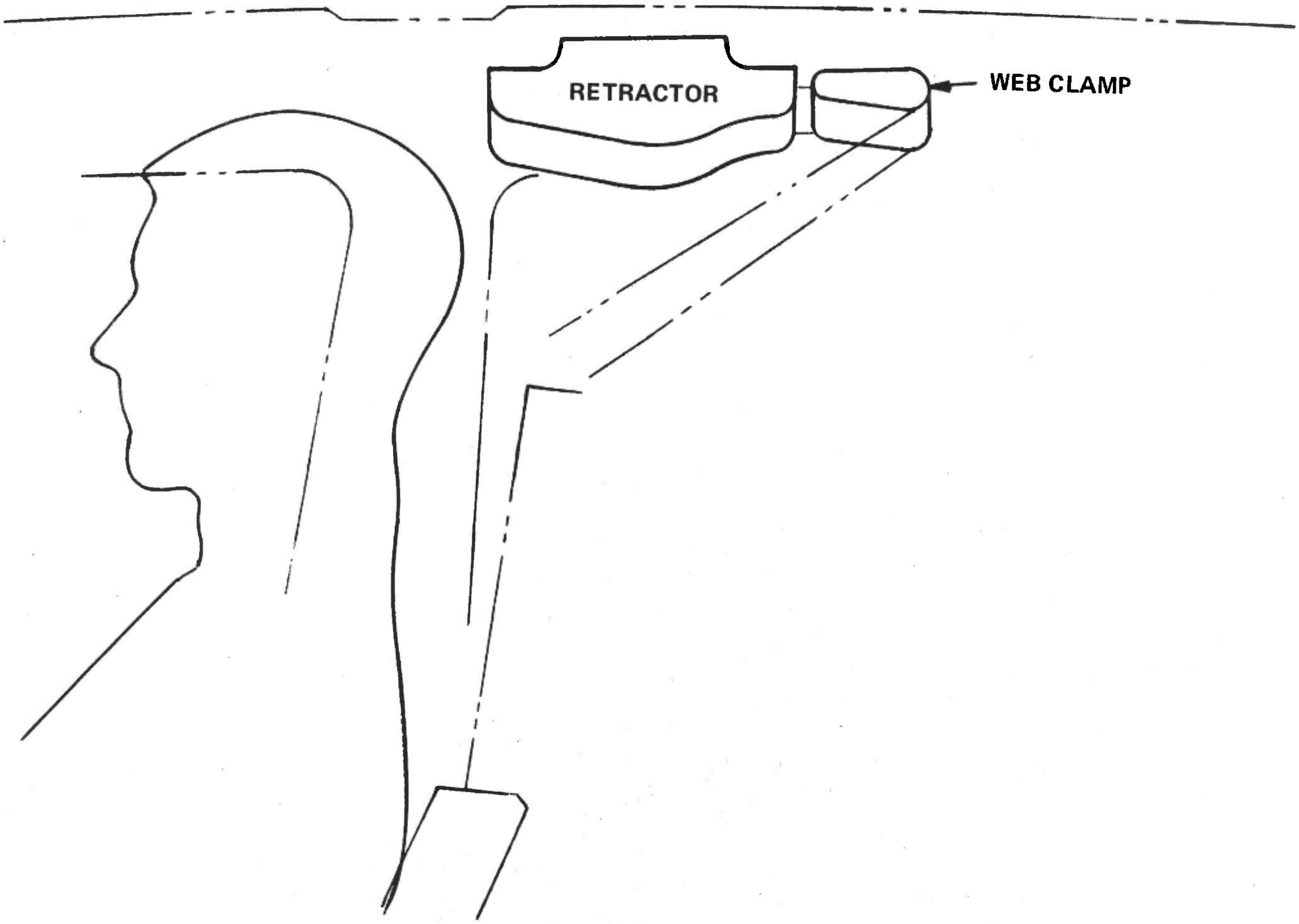
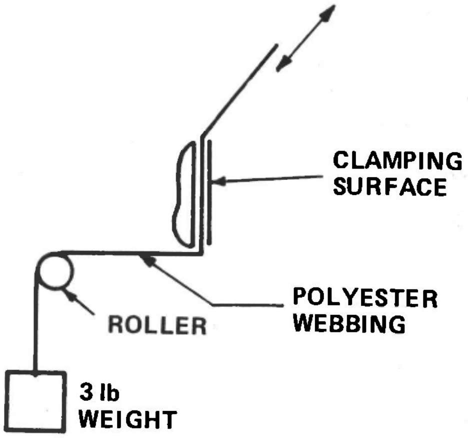


Figure 5 RETRACTOR AND WEB CLAMP LOCATION, EARLY PHASE III

The passive operation of the air belt restraint system would also require repetitive motion of the torso belt webbing through the web clamp. To assess the webbing abrasion effects of this installation, tests were performed at Allied employing the procedure used routinely for buckle abrasion tests.

Polyester webbing routed through the web-clamp was deflected so as to force the belt onto the clamping surface. A three pound weight provided belt tension. The sketch below illustrates essential element of the test setup.



The webbing was cycled at 18 cycles/minute for a total of 10,000 cycles. For reference, buckle tests are performed for a total of 2500 cycles.

Three samples were tested, and at completion they showed no significant deterioration having acquired only a slight shiny appearance. The samples were then pulled to failure and showed no decrease in their ultimate load capability.

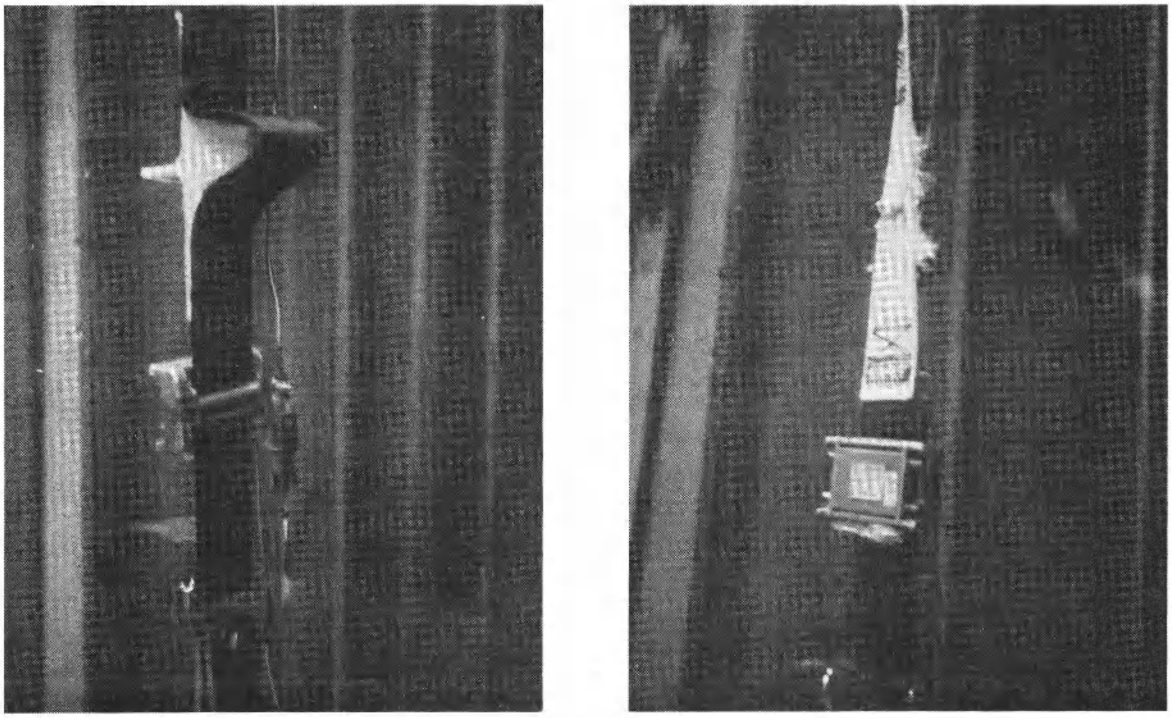
3.2 Load Limiter Testing

Two replacements for the mechanical force limiters used in Phase II testing were evaluated. A load limiter woven to tear apart in a controlled manner was supplied by the Allied Automotive Products Division. A sample of this limiter, before and after testing, is displayed in Figure 6. This limiter would be incorporated into the air belt design in a manner similar to that depicted in Figure 6; i.e., it would be sewn to conventional polyester webbing that goes from the roof rail retractor to the end of the inflatable portion of the air belt.

The other load limiter investigated was a 20 percent elongation belt webbing designed and manufactured for Calspan by the Takata Kojyo Co., Ltd. of Tokyo, Japan. Desired force deflection properties were woven directly into this belt webbing. A post test sample of a yielded piece of this webbing is displayed in Figure 7. The mode of integration of the Takata force limiting webbing into the air belt design would be a straight forward replacement of the conventional belt.

Geometry constraints imposed by the web clamp location and passive operation requirements of the air belt indicated that only three to four inches of load limiter stroke could be attained with either of the two designs. Data developed during Phase II sled testing had been reviewed to determine the required force level for the limiter as a function of available stroke. These data, for 50th percentile male size dummies, are displayed in Figure 8. The force-stroke correlation appears to be very good even though test points with and without lap belts are included. These data indicated that a 1900 to 2000 pound force limiter could provide acceptable dummy performance at speeds approaching 50 mph.

Static tensile and dynamic drop tests were conducted with samples of both Allied and Takata limiters. During this test period, a number of problems were experienced with the Allied load limiters. The force level of the initial batch of samples was too low (1200-1300 pounds). Furthermore, the onset rate was poor. Continued testing indicated that pre-tearing the specimens was required to improve this situation. A number of delivery delays were encountered during this period, and a single 2000 pound limiter was never developed. Instead, two 1000 pound limiters were sewn in parallel.



PRE-TEST

POST-TEST

Figure 6 TEAR WEBBING LOAD LIMITER TEST SAMPLE

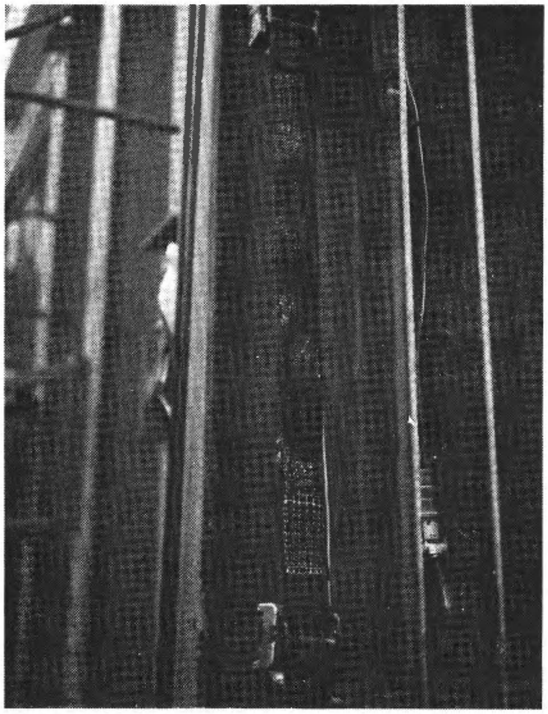


Figure 7 TAKATA LOAD LIMITING WEBBING SAMPLE

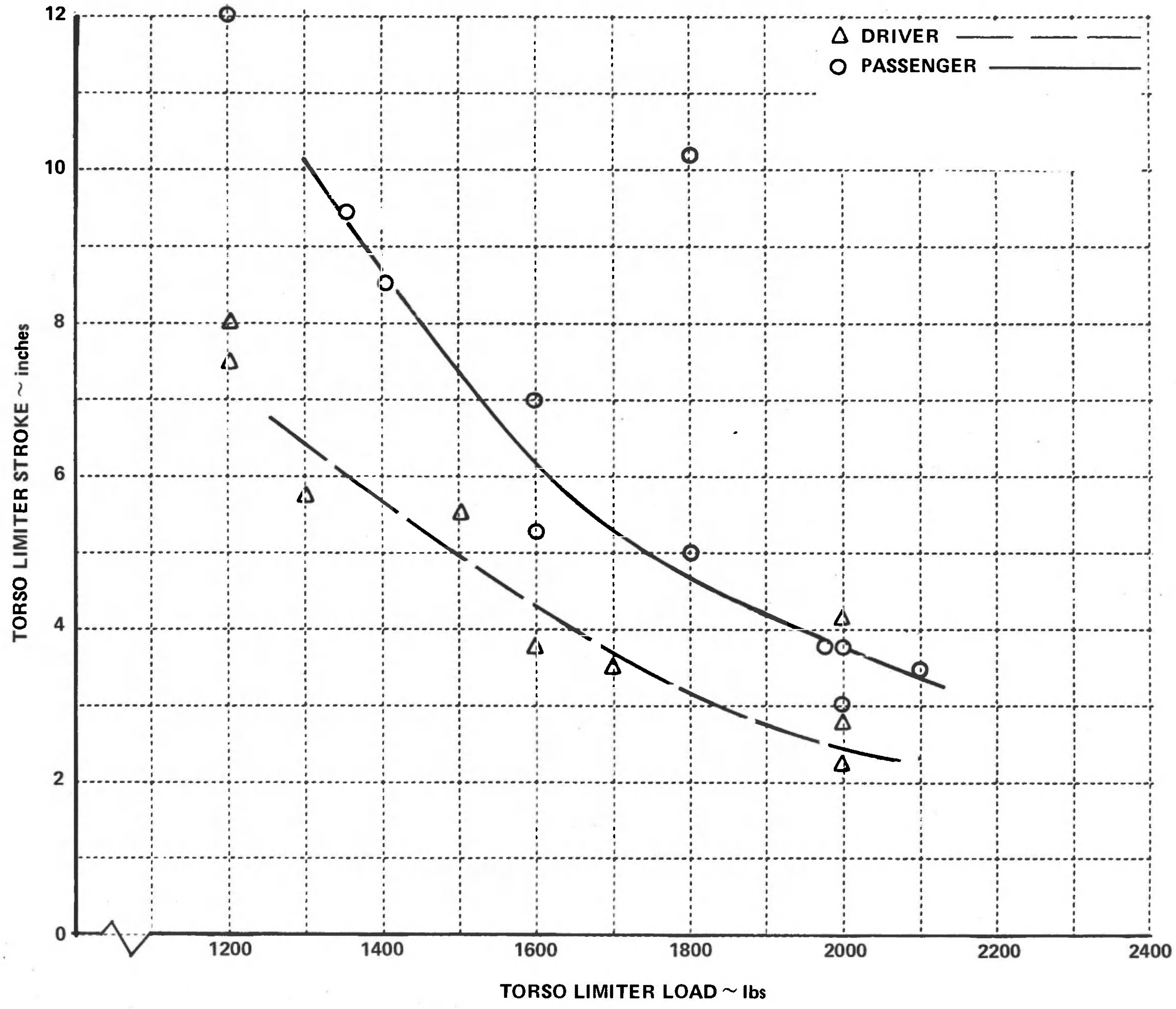


Figure 8 RSV LOAD LIMITER STROKE REQUIREMENTS
50 MPH BARRIER IMPACT
50th pct OCCUPANTS

Component testing of the Takata webbing samples, on the other hand, was straightforward. No delays or performance problems were experienced.

Comparisons of the dynamic performance of the final Allied limiter design, the Takata webbing, and the Phase II mechanical limiter are presented in Figure 9. The Allied and Takata limiters were also tested under conditions that exceeded the rated stroke length of the samples in order to assess performance under an overloaded condition. The results, presented in Figure 10, indicate that either limiter would still provide acceptable performance in such a situation.

As a result of these tests, it was concluded that although either limiter was satisfactory from a performance standpoint, only the Takata Kojyo limiter was acceptable from a producibility capability. Problems were experienced in passively deploying the air belt with the Allied limiter, while integration of the Takata webbing into the air belt design was very simple and straightforward.

3.3 Selection of an Inflator

Two pyrotechnic inflators were examined for integration into the air belt system. They were an Allied inflator specifically designed for the RSV, and a production Thiokol driver unit uploaded from 94 to 110 grams of propellant.

A series of static deployment tests was performed at Calspan to evaluate the performance of both inflators. The Thiokol inflator tested was the same unit that is currently being used for the RSV driver air bag system. Note, that in the air belt application a single unit is used to inflate both driver and passenger air belts.

For these tests, a 50th percentile dummy was seated in the driver position of the RSV sled buck. The driver air belt was deployed about the dummy while the passenger belt was left free. Web clamps and roof mounted retractors were employed. Fifty percent porous as well as non-porous bags were tested. The results of the tests are summarized in Table 2.

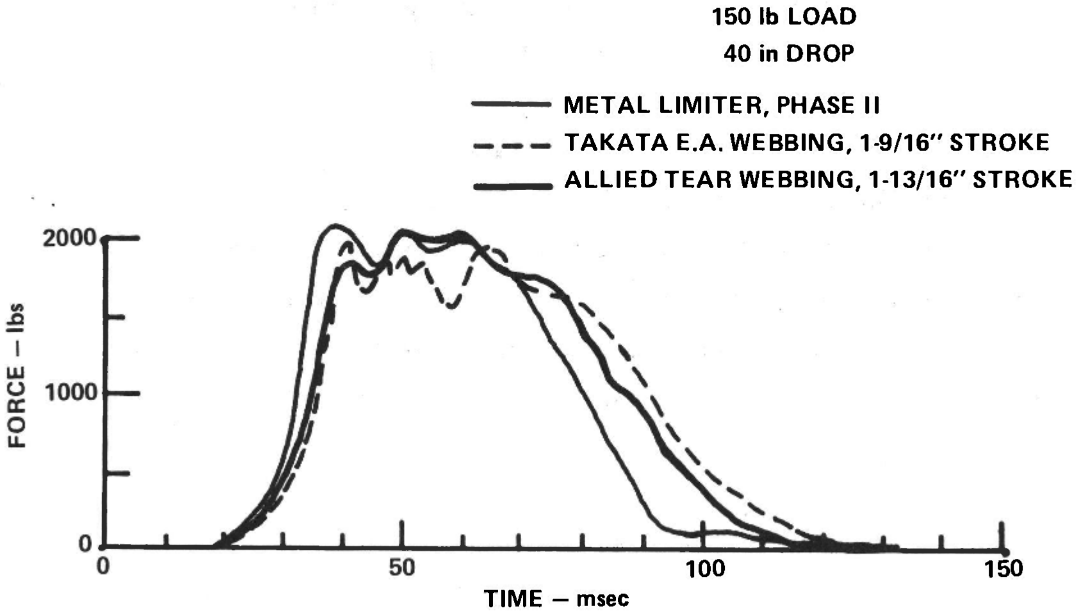


Figure 9 LOAD LIMITER PERFORMANCE DYNAMIC TEST RESULTS

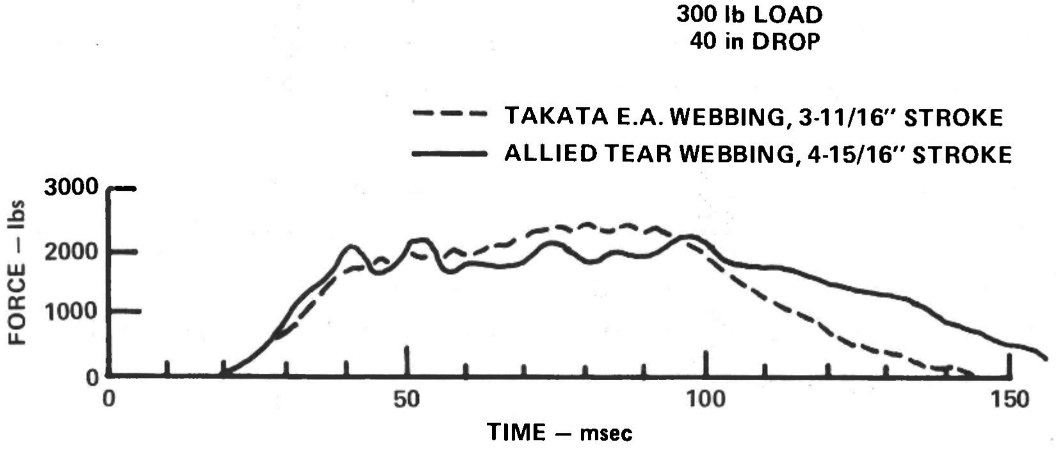


Figure 10 LOAD LIMITER PERFORMANCE DYNAMIC TEST RESULTS

TABLE 2

STATIC DEPLOYMENT TEST RESULTS

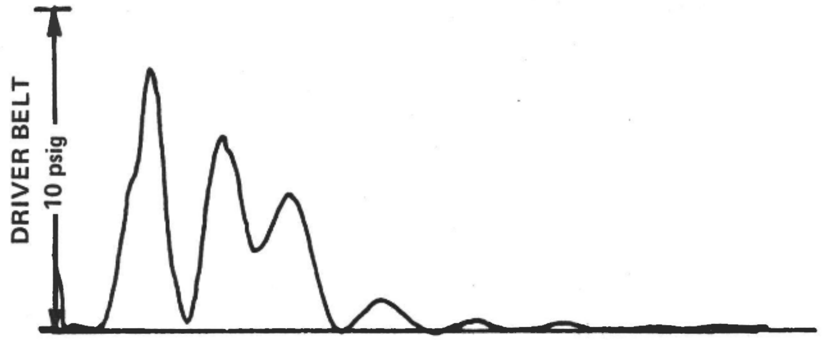
Test No.	Inflator	Bag Porosity	Driver Pressure	Passenger Pressure	Comments
1	Allied	50%	6.4 psig	3.1 psig	Both bags ruptured
2	Thiokol	50%	5.8	3.5	
3	Thiokol	0		3.4	Misplaced driver tube
4	Thiokol	0	8.0	7.2	
5	Allied	50%	3.9	5.2	Burned out passenger bag
6	Allied	0		3.5	Driver tube misplaced Burned out passenger bag
7	Allied	0	7.8	4.6	Driver bag slight holes Burned out passenger bag

Figure 11 provides data comparing the pressure time history for the air belt static inflation tests with both Allied and Thiokol inflators. These results indicate that comparable pressure performance could be obtained from either system. However, with the Allied system, the temperature of the exit gas was unacceptable, burning holes through the air belt in six of seven test firings. Figure 12 presents pressure time history data for non-porous air belts using the Thiokol inflator.

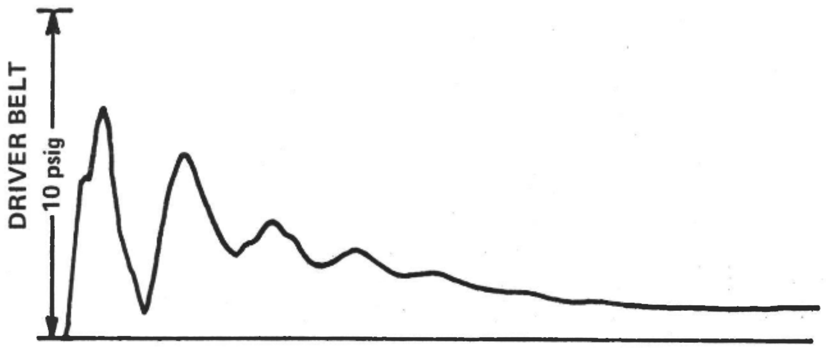
Typically, the air belts were inflated in 25 milliseconds with unvented pressures of 7 to 8 psig. Induced belt tension loads were nominally 200 to 300 pounds.

Phase II static firings with the stored gas inflator had resulted in pressures of approximately 10 psig. At the conclusion of the inflation tests, therefore, there was some question as to the belt inflation pressure requirements for optimum restraint. A series of belt tension tests was conducted on air belt samples to determine the force deflection properties of the air belt both in an uninflated condition and at various initial inflated pressures. One result of these tests is presented in Figure 13. Belt force or pre-load is plotted as a function of air belt pressure. This result indicates that above 1 to 2 psig the air belt is fully inflated (and thereafter experiences little change in shape with increasing belt pressure). Consequently, belt preload also changes little above 1 to 2 psig. It was concluded from these tests that the belt pressures obtained with the Thiokol system were adequate to fully inflate the air belts.

It was also concluded that it would be preferrable to initiate sled testing with non-porous air belts and to introduce venting holes rather than bag porosity as a method of accurately controlling the venting which could be required.



TEST 1 ALLIED – POROUS



TEST 2 THIOKOL – POROUS

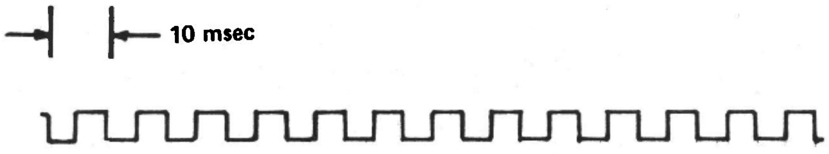


Figure 11 AIR BELT STATIC FIRING TESTS

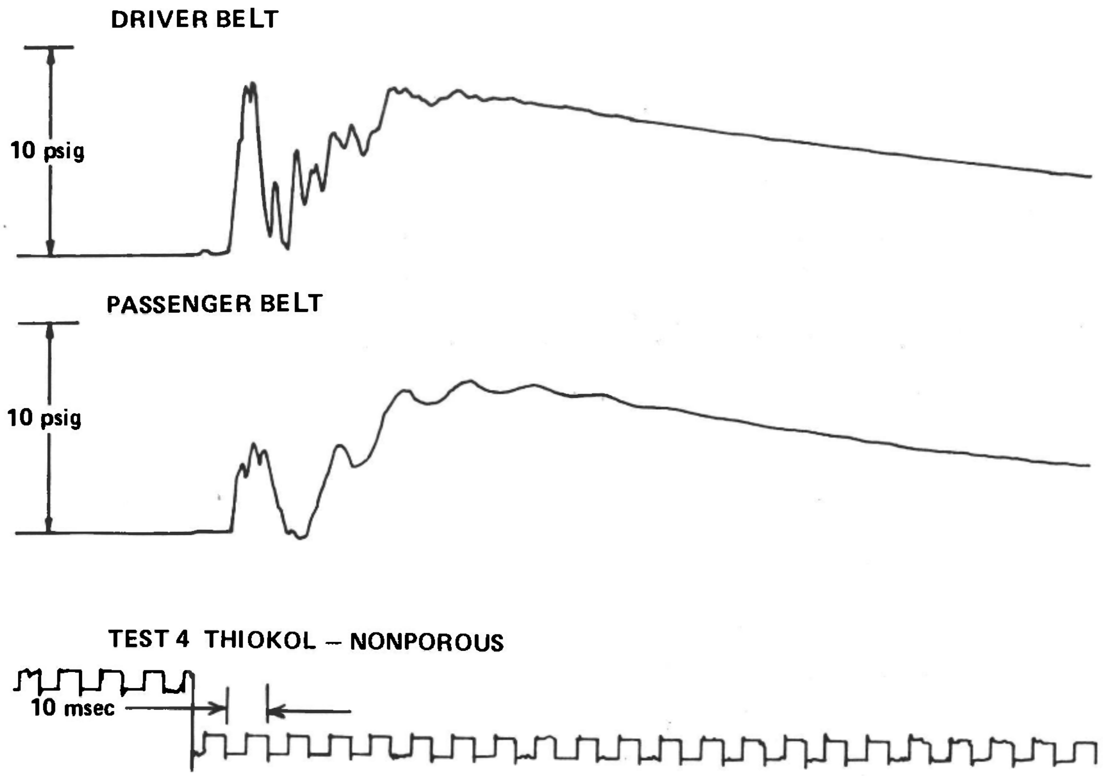


Figure 12 AIR BELT STATIC FIRING TESTS

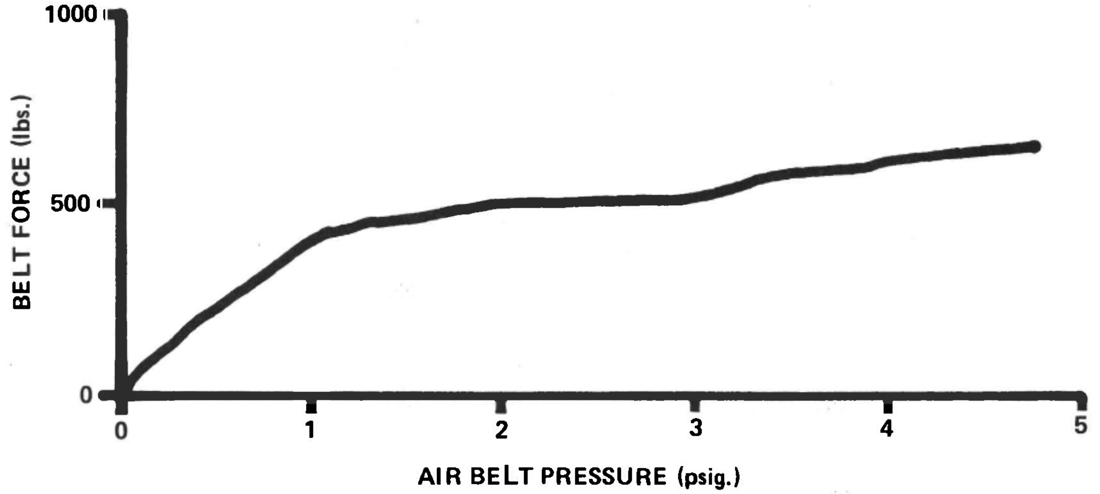


Figure 13 BELT PRETENSIONING AS A FUNCTION OF AIR BELT PRESSURE

3.4 Phase III Preliminary Air Belt Design

As mentioned previously, while the candidate components were being tested, they were simultaneously being mocked up in a RSV base vehicle. At the conclusion of testing and evaluating the inflators, load limiters and web clamp, a preliminary integrated air belt design was available.

This system is illustrated in Figure 14. Starting from the top end of the system and working down, this system included:

- Air Belt Retractor - roof mounted standard production 1976 GM A Body retractor; vehicle sensitive.
- Takata Force Limiting Webbing - 20% elongation, 1875 pound yield level, spooled on retractor and sewn to upper end of inflatable portion of air belt.
- Web Clamp - developed by Allied, located on roof rail aft of retractor.
- D Ring - located on roof rail forward of retractor; non-structural, capable of breaking loose.
- Inflatable Portion of Air Belt - 7.4 inch diameter x 28 inch long neoprene coated nylon bag; 24 Warp x 24 Fill. No gas venting.
- Polyester Webbing - standard production, 6% elongation (@ 2500 pounds); sewn to lower end of inflatable belt and attached to tunnel anchor point.
- Manifold Tubing - extruded teflon tube with stainless steel single wire braid cover; ports gas from manifold to inflatable portion of belt.

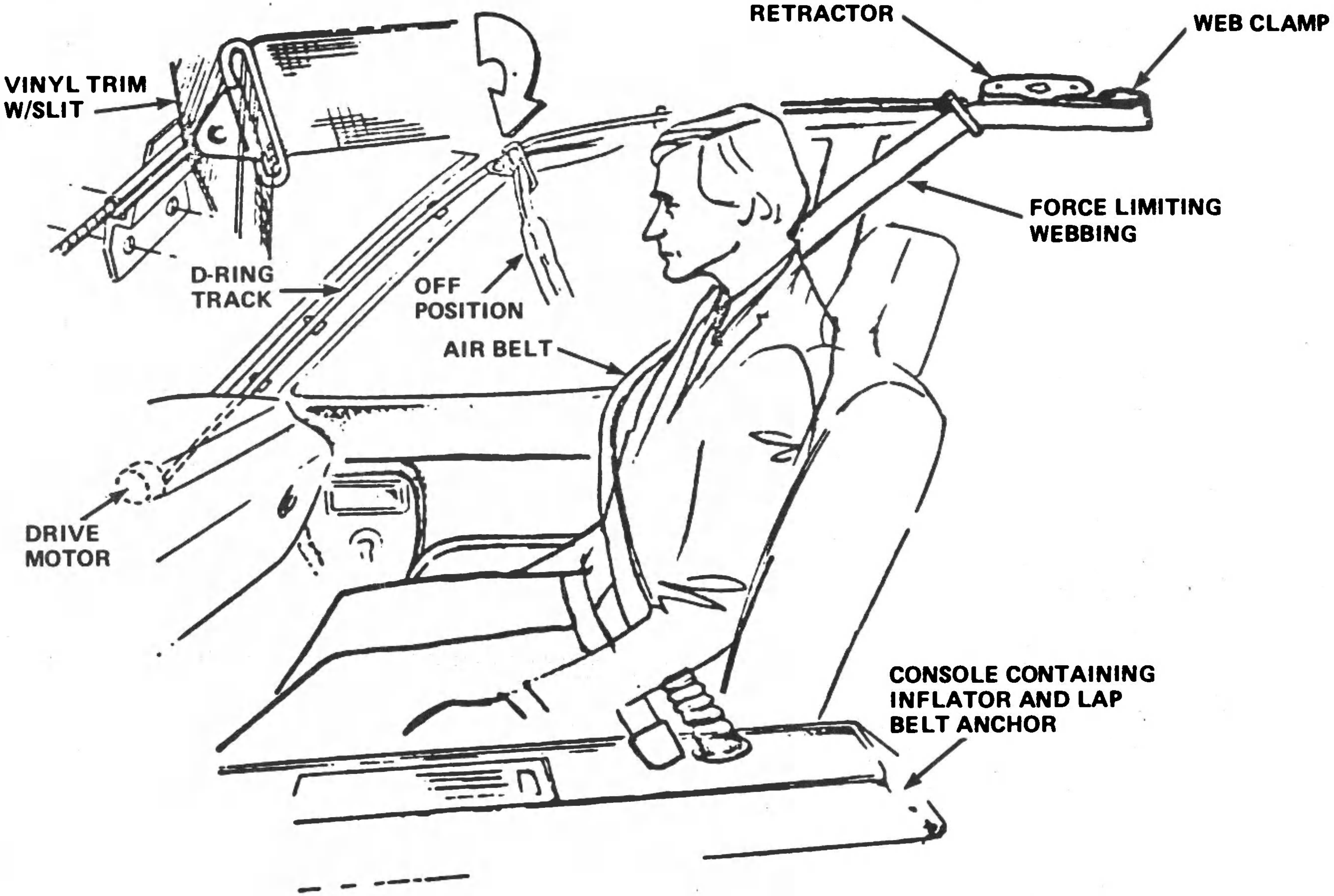


Figure 14 INITIAL PHASE III RESTRAINT GEOMETRY

- Manifold - designed at Calspan to accept Thiokol inflator; anchored to tunnel between seats; two ports, one for each air belt.

- Inflator - Thiokol 110 gram uploaded inflator, .7 inch screen pack height.

In addition to the air belt, an active lap belt was included. The lap belt retractor was supplied by Takata Kojyo and spooled with 500 to 700 pound force limiting webbing. The low force level was chosen so that passive system performance (air belt) would not be dependent on lap belt use. The role of the lap belt was to prevent ejection in side impacts and rollovers. Clearly, improved performance of the passive system through use of the lap belt was acceptable.

The above system constituted the starting point design for developmental sled testing.

4.0 DEVELOPMENTAL SLED TESTING

Twenty-seven sled tests were conducted in support of RSV air belt restraint system development. Twenty-four of these runs had two dummy occupants in either a driver/passenger or passenger/passenger configuration. Three additional passenger air belt exposures were obtained coincident with RSV driver air bag testing. Thus, data from a total of 51 occupant impact exposures were generated.

As a result of this testing, final RSV air belt restraint system hardware and geometry were defined. The significant differences between the preliminary and final system design were the elimination of the web clamp, a redesign of the method of fabrication of the inflatable belt, and the addition of structural B pillar and seat frame D rings.

4.1 Description of Test Set Up

Pre-test photographs of a typical sled set up and a 46 mph sled pulse are depicted in Figures 15 and 16. All of the sled tests were performed with the Phase II RSV body buck and metering pin. Testing began with all of the air belt restraint components detailed in Section 3.4. Lap belts were not employed, because only the air belt design is passive. The Thiokol inflator was electrically activated 13 milliseconds after 1 g of sled deceleration. This time delay was based upon the sensor closure data obtained from the Phase II full scale crash tests. Lastly, the RSV instrument panel was simulated by a rigid boiler plate frame supporting collapsible aluminum honeycomb knee restraint inserts.

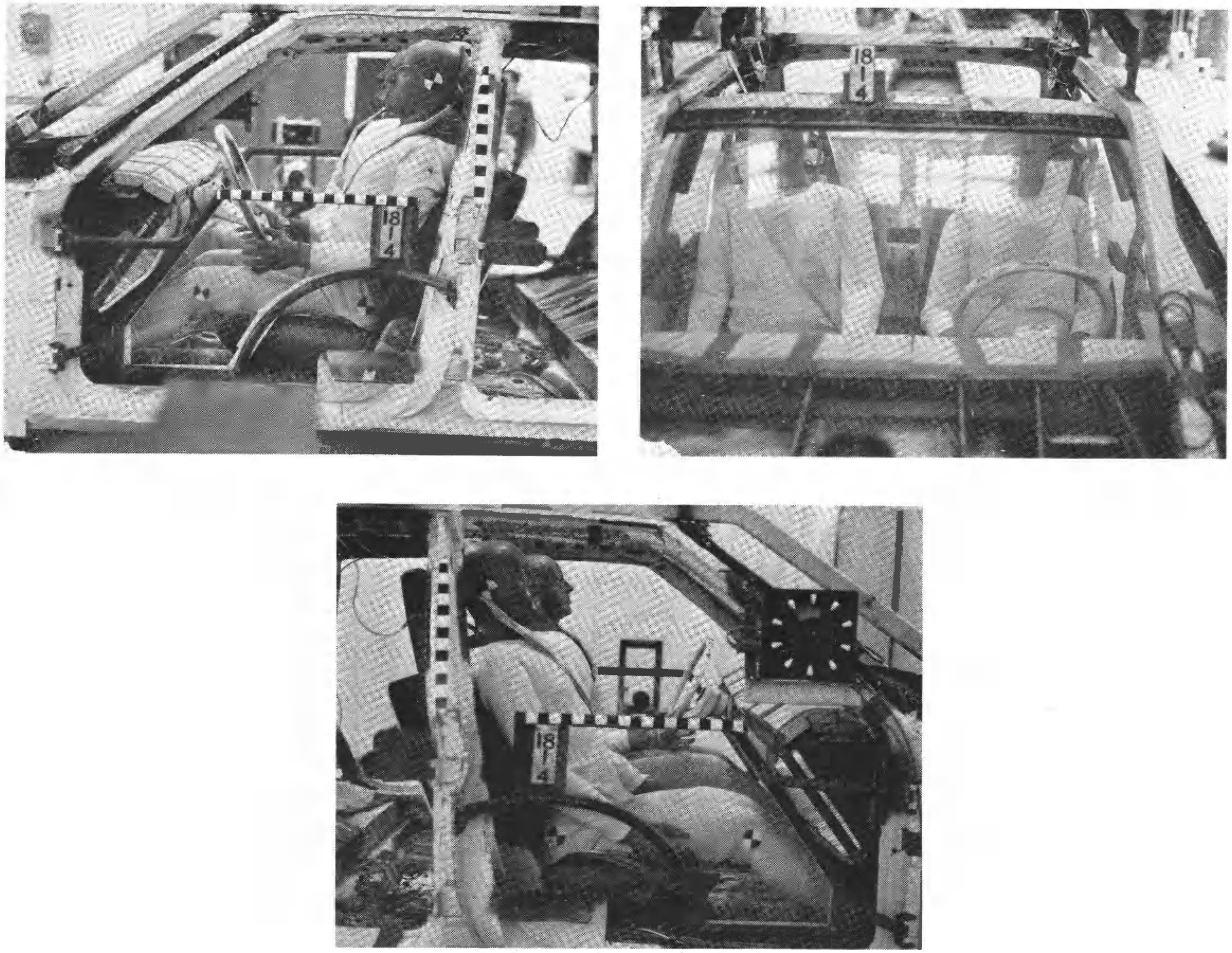


Figure 15 PRE TEST PHOTOS OF INITIAL DEVELOPMENTAL SLED TEST CONFIGURATION

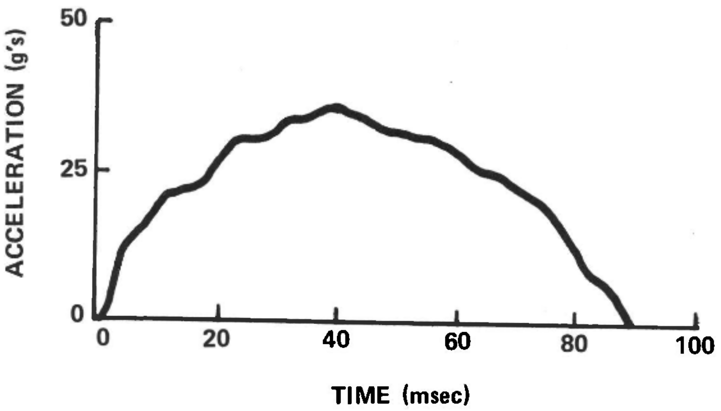


Figure 16 TYPICAL 46 MPH SLED PULSE

4.2 Test Results

The results of the developmental sled tests have been summarized in Table 3. With the exception of the first two sled runs, all the 50th percentile occupant demonstrations were conducted at approximately 46 mph. Fifth percentile female and 95th percentile male tests were performed at 41 mph. In the following paragraphs, discussions detailing the progression to the final air belt restraint design are presented.

As referred to previously, Figure 14 depicts the initial configuration chosen for sled testing. A primary performance objective of this layout was to improve ridedown and thus reduce the required occupant travel space. The roles played by the web clamp and air belt to reduce spooloff and slack were alluded to previously. Also of significance is the line of action of the air belt with respect to the occupant.

Initial sled testing did, in fact, demonstrate an influence of anchor point position on effective restraint stiffness. For sled Runs 1814 through 1817 the restraint appeared to be stiffer than necessary. The

Table 3
RSV AIR BELT DEVELOPMENT TEST RESULTS

TEST CONDITIONS					RESTRAINT CONDITIONS			DUMMY		DUMMY DATA								RESTRAINT DATA		
										HEAD			CHEST		PELVIS	FEMUR LOAD lbs.				
DATE	RUN NO.	VEL. MPH	MAX G	STROKE (inch)	CONFIG.			SIZE	POSITION	H_R	HSI	HIC	C_R	CSI	P_x	L	R	KNEE BAR L R (inch)	BAG PRESSURE (psi)	
7/12	1814	41.2	30.8	35.4	D rings	No Inflation		50th	Dr.	100	1380	1063	72	700	76	1800	1880	3-5/8 3-1/8	Uninflated	
								50th	Pass.	86	770	545	56	680	64	1800	2040	3-1/8 2-5/8	Uninflated*	(1)
7/12	1815	41.5	31.8	35.5	Web Clamps			50th	Dr.	82	1040	749	62	640	72	2240	2000	3-3/8 3	10	(2)
								50th	Pass.	70	700	573	55	515	60	1650	1900	2-5/8 3	16	
7/13	1816	45.2	33.9	36.6	Web Clamps			50th	Dr.	72	1200	977	52	525	78	1850	1800	3-3/8 3	25/18	(3)
								50th	Pass.	100	1120	859	54	620	68	1750	1950	2-7/8 3	25	
7/14	1817	45.9	35.5	37.1	Web Clamps	New Hose		50th	Dr.	60	1000	840	64	800	90	2240	2080	3-3/4 3-5/8	18	(4)
								50th	Pass.	80	1000	829	66	740	74	1840	2050	3 3-1/4	18	
7/18	1818	46.0	36.3	37.0	Web Clamps	D ring on seat		50th	Dr.	68	1000	906	66	880	80	2160	2040	3 3	16	
								50th	Pass.	76	860	706	60	720	72	1800	2000	3-3/8 3	24	
7/18	1819	46.4	35.4	36.8	Web Clamps	Inflated portion of air belt rotated about occupants 6" outboard.		50th	Dr.	80/ 158		1846	43 / 62		84	2180	2250	3-1/8 3-1/4	19	(5)
								50th	Pass.	66/ 100	2580	1613	37 / 74		68	1840	2160	3-1/8 3-1/2	23.5	

(1) D ring severed passenger upper belt
(2) Inflator broke away from manifold
(3) Inflator hoses plugged up due to Teflon inner liner crimping and melting
Tear in driver bag at pressure insert hole
(4) C_R does not include C_Y component
(5) Both belts failed at upper belt attachment point. Web clamp severed Passenger webbing.

Table 3

RSV AIR BELT DEVELOPMENT TEST RESULTS (Cont.)

TEST CONDITIONS					RESTRAINT CONDITIONS	DUMMY		DUMMY DATA								RESTRAINT DATA			
								HEAD			CHEST		PELVIS	FEMUR LOAD lbs.					
DATE	RUN NO.	VEL. MPH	MAX G	STROKE (inch)	CONFIG.	SIZE	POSITION	H_R	HSI	HIC	C_R	CSI	P_x	L	R	KNEE BAR L (inch)	KNEE BAR R (inch)	BAG PRESSURE (psi)	
7/18	1820	46.3	35.4	36.5	Reinforced transverse stitching added,	50th	Dr.	80/ 88	600/ 2000	1392	44/ 60		80	2400	2200	3-5/8	4	22.5	(1)
					Web Clamps	50th	Pass.	72/ 120	920/ 1700	1110	47	500	68	1800	1880	3-1/2	4-1/8	31	
7/19	1821	45.5	36.5	36.8	Repeat of 1819 sans web clamps,	50th	Dr.	67	800	691	66	900	86	2360	2200	2-7/8	3	19.8	(2)
					D rings used	50th	Pass.	74	960	1007	60	740	76	2000	2000	2-7/8	3	24.5	
7/21	1822	46.2	36.8	36.4	D rings replaced by rollers	50th	Dr.	70	700/ 950	551	80	840	88	2320	2000	2-7/8	2-7/8	18.5	(3)
						50th	Pass.	60/ 200	1000/ 2000+		44/ 120	400/ 2000+	84	1880	2000	2	3-1/4	24.5	
8/5	1834	45.2	36.0	36.7	Modified bag, webbing sewn 1 ft. down on each side of bag	50th	Pass.	54/ 72	620	485	54	520	88	1900	2200	2-1/8	2-3/8	22	(4)
8/8	1835	46.0	36.4	36.9	Belt sewn to one side all the way	50th	Pass.	108	2450	1663	59	680	76	1960	2200	2-3/4	2-5/8	20.5	(5)
8/9	1836	45.5	37.3	36.7	Belt sewn both sides all the way	50th	Pass.	84	1400	1074	60	820	72	1900	2000	2-3/4	3-1/4	20	(6)

(1) Driver belt tore at web clamp.
Passenger airbelt material severed at upper stitching
(2) Two inch tear on upper portion of belt (bag); D rings bent 90°.
(3) Passenger belt pulled out of bag. Driver bag tore at juncture.
(4) Belt tore off at end of internally sewn webbing.
(5) Bag ripped open at top
(6) Unused bag separated from manifold

Table 3

RSV AIR BELT DEVELOPMENT TEST RESULTS (Cont.)

TEST CONDITIONS					RESTRAINT CONDITIONS		DUMMY		DUMMY DATA									RESTRAINT DATA		
									HEAD			CHEST		PELVIS	FEMUR LOAD lbs.					
DATE	RUN NO.	VEL. MPH	MAX G	STROKE (inch)	CONFIG.		SIZE	POSITION	H_R	HSI	HIC	C_R	CSI	P_x	L	R	KNEE BAR L (inch)	KNEE BAR R (inch)	BAG PRESSURE (psi)	
8/9	1837	45.8	36.3	36.6	2 Pass. (Dr.) 2" pleat in bac, belt all the way		50th	Pass (Dr.)	140			72	930		2000	1820	2-1/2	2-3/4	14	(1)
					Loose belt in inflatable portion		50th	Pass.	114			72	920	83	1840	2240	2-7/8	3-3/4	13.5	
8/10	1838	45.9	36.7	36.6	Pass. (Dr.)	50% porous Allied belt	50th	Pass. (Dr.)	250			66	880		2100	2000	2-7/8	2-1/2	14.6	
					Pass.	100% porous Allied belt	50th	Pass.	116		1700	73	900	84	1760	2100	3	3-3/8	16.5	
8/11	1839	45.8	36.8	36.9	Pass. (Dr.)	Webbing sewn to both sides	50th	Pass. (Dr.)	66/ 100	300	1086	73	950		2000	2000	2-7/8	2-5/8	25	
					Pass.	Same with web clamp	50th	Pass.	67/ 86	1000	956	65	800	76	1900	2200	2-7/8	3-3/8	19	
8/16	1844	46.0	36.2	36.8	Roller aft 6", 14.5" webbing to roller		50th	Pass. (Dr.)				62	850		2000	1920	2-5/8	2-1/2	18.5	(2)
					Belt rotated In board 3" 12.5 webbing to roller		50th	Pass.	120	1240	857	64	800		2260	2320	2-7/8	3	12.5	
8/17	1845	45.7	37.0	37.0	Roller aft 6",14.5" webbing		50th	Pass. (Dr.)	73/ 100+	1000/ 185+	1431	64	840		2160	2160	3	3	15.0	(3)
					Roller aft 6"; belt in board 3", 18" webbing		50th	Pass.	98/ 100+	1440/ 2000+	2323	66	820		1940	2160	3	3	11.5	
8/18	1846	45.8	36.6	36.9	Roller 6" aft, 14.5" webbing		50th	Dr.	58/ 100+	1200	940	74	960		2440	2080	2-3/8	2-1/8		(4)
					D ring 6" aft, 14.5" webbing		50th	Pass.	54/ 97	950	749	49	550		2160	2320	2-5/8	2-5/8		

(1) Both bags separated at top from belts
(2) Driver head failure. Head was probably damaged in car crash on previous day
Passenger retractor malfunctioned – belt released.
(3) Pressure data lost after 45 msec for driver.
(4) Pressure data lost on both sides.

Table 3

RSV AIR BELT DEVELOPMENT TEST RESULTS (Cont.)

TEST CONDITIONS					RESTRAINT CONDITIONS	DUMMY		DUMMY DATA								RESTRAINT DATA			
								HEAD			CHEST		PELVIS	FEMUR LOAD lbs.					
DATE	RUN NO.	VEL. MPH	MAX G	STROKE (inch)	CONFIG.	SIZE	POSITION	H_R	HSI	HIC	C_R	CSI	P_x	L	R	KNEE BAR L (inch)	KNEE BAR R (inch)	BAG PRESSURE (psi)	
8/19	1847	45.7	36.7	36.9	D ring 6" aft	50th	Dr.	66/ 100+	960/ 1850	1521	68	940		2320	2400	2-1/2	2-1/2	16	(1)
					D ring 6" aft	50th	Pass.	80/ 100+	1000/ 1920	1917	56	690		2160	2300	3	3-1/8	24.5	
8/29	1862	45.7	36.8	36.6	D ring also on B pillar; 6" belt on spool.	50th	Pass. (Dr)	52	900	655	60	745		2050	1900	3	3	24.5	
					D ring also on B pillar; 6" belt on spool.	50th	Pass.	60	860	675	49	550		2150	2150	2-7/8	2-3/4	22.5	
8/30	1863	45.6	37.1	36.5	Same as above	50th	Dr.	55	960	748	62	750			2300	2-1/8	2-1/2	24	
					Same as above	50th	Pass	69	500	809	54	600		2200	2200	2-7/8	3	25	
8/31	1864	46.0	37.5	36.9	24" belt on spool	50th	Dr.	80	1040	929	61	780		2400	2100	2-1/4	2-1/4	24	
					24" belt on spool	50th	Pass.	200+	2000+	2455	56	595		2150	2000	2-1/2	3	21.5	
9/1	1865	45.8	36.9	37.0	18" belt on spool	50th	Dr.	94	1600	1277	58	700		2250	2300	2-1/4	2-1/4	22.5	
					18" belt on spool	50th	Pass.	74	1040	810	60	660		2100	1900	2-1/2	3	25.0	
9/2	1866	45.9	37.7	36.6	18" belt on spool, RSV dash (5 msec squib)	50th	Dr.	80	1420	1230	60	780		2250	950	3	1-5/8	22	
						50th	Pass.	60	1000	985	58	720		950	1500	2-1/8	2-1/4	23	

(1) 3 inch slits on passenger bag at pressure tap insert location (≈ 60 msec)

Table 3

RSV AIR BELT DEVELOPMENT TEST RESULTS (Concl'd)

TEST CONDITIONS					RESTRAINT CONDITIONS			DUMMY		DUMMY DATA								RESTRAINT DATA	
										HEAD			CHEST		PELVIS	FEMUR LOAD lbs.			
DATE	RUN NO.	VEL. MPH	MAX G	STROKE (inch)	CONFIG.			SIZE	POSITION	H_R	HSI	HIC	C_R	CSI	P_x	L	R	KNEE BAR L R (inch)	BAG PRESSURE (psi)
9/6	1867	45.7	38	36.5		1.0" diameter vent		50th	Dr.	85	1540	1313	55	640		2250	2100	2 2	18.5
						1.0" diameter vent		50th	Pass.	94	1600	1211	67	835		2150	2200	2 2	16.5
9/7	1868	41.4	30.9	35.8				95th	Dr.	76	1300	1124	54	540		2000	1900	2-1/4 2-1/4	21.5
								5th	Pass.	74/100	1000/2000	1616	160	2000+		1000	900	2 1-3/4	20
9/8	1869	41.4	31.4	35.8				5th	Dr.	66/85	1090/1600	1273	82	1200		1500	1550	1-3/4 1-1/2	15
					18" belt on spool			95th	Pass.	115	1100	1353	52	550		2150	1850	2-1/2 3-1/4	21

(1) Seam tear at upper attachment point of airbelt (4" long).

inflatable portion of the air belt rode up the inboard side of the occupant's chest. In addition, the upper portion of the inflatable belt was too low with respect to the occupant's head. Better load distribution of the air belt about the occupant was needed.

As a first step, the inboard portion of the air belt was prevented from riding up the dummy's torso. This was accomplished by routing the polyester webbing (sewn to the inboard portion of the air belt) through a D ring fixed on the seat frame. The floor pan anchor point for the webbing was retained. In this manner, the inboard placement of the air belt was properly aligned on the occupant and remained so regardless of seat position.

Use of the seat mounted D ring resulted in improved occupant kinematics and performance for Run 1818. The 50th percentile passenger passed all the injury criteria at 46 mph while the driver slightly exceeded the chest criteria.

Film data indicated that the restraints were still very stiff and that the upper portion of the inflatable belt was still providing minimal head restraint. To improve the positioning of the air belt with respect to the outboard portion of the occupant's upper torso, the inflatable part of the belt was rotated six inches outboard (Run 1819). This reduced the Takata force limiting webbing available for stroking from 16 to 10 inches.

Initial deployment of the air belts looked good in Run 1819; improved head restraint was evident. However, very serious air belt construction problems were encountered. Stitching and air belt material failure occurred for both the driver and passenger systems at the Takata webbing/air belt juncture. In addition, the web clamp for the passenger system severed the Takata force limiting webbing.

In the subsequent three sled tests (Runs 1820, 1821, 1822), reinforced stitching was added, the web clamps were replaced by D rings, and the D rings were replaced by rollers, respectively. However, failures at the upper attachment point of the air belt continued as well as an additional belt failure at the web clamp.

At this point, representatives of Irvin Industries in Fort Erie, Canada, were contacted because of their considerable expertise in the field of sewing restraint harnesses. Based upon their suggestions, five progressively stronger air belt designs were fabricated and tested. Only the final concept proved strong enough.

Figure 17 illustrates the initial and final versions of the air belt design. Bag material remained the same (24 Warp x 24 Full neoprene coated nylon). However, the following modifications were made:

- transverse stitches were eliminated
- the top of the belt was tapered
- a nylon reinforcement collar of air belt material was wrapped around the upper end prior to sewing
- two pieces of belt webbing were symmetrically sewn along the entire inside length of the inflatable portion of the belt

Air belts were contructed in this manner for the remainder of the testing.

Once the final sewing design for the inflatable portion of the air belt was obtained (Runs 1834-1838), a direct comparison was made of passenger performance with and without a web clamp in Run 1839. For the passenger on the driver side of the sled buck, the web clamp was replaced by a roller.

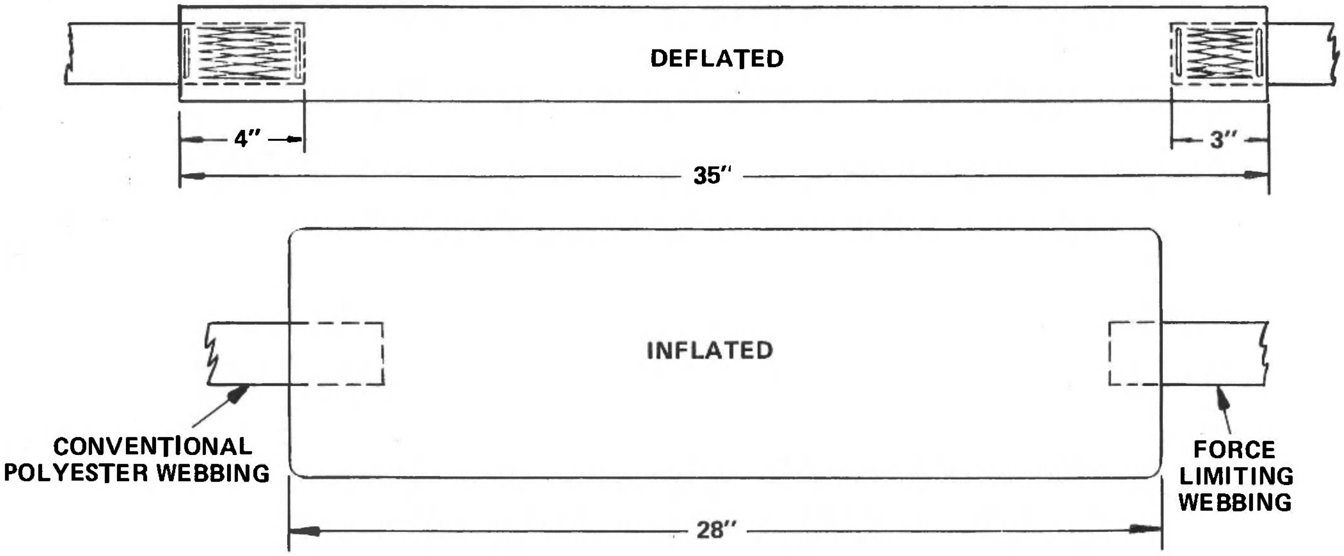


Figure 17a INITIAL PHASE III AIR BELT DESIGN

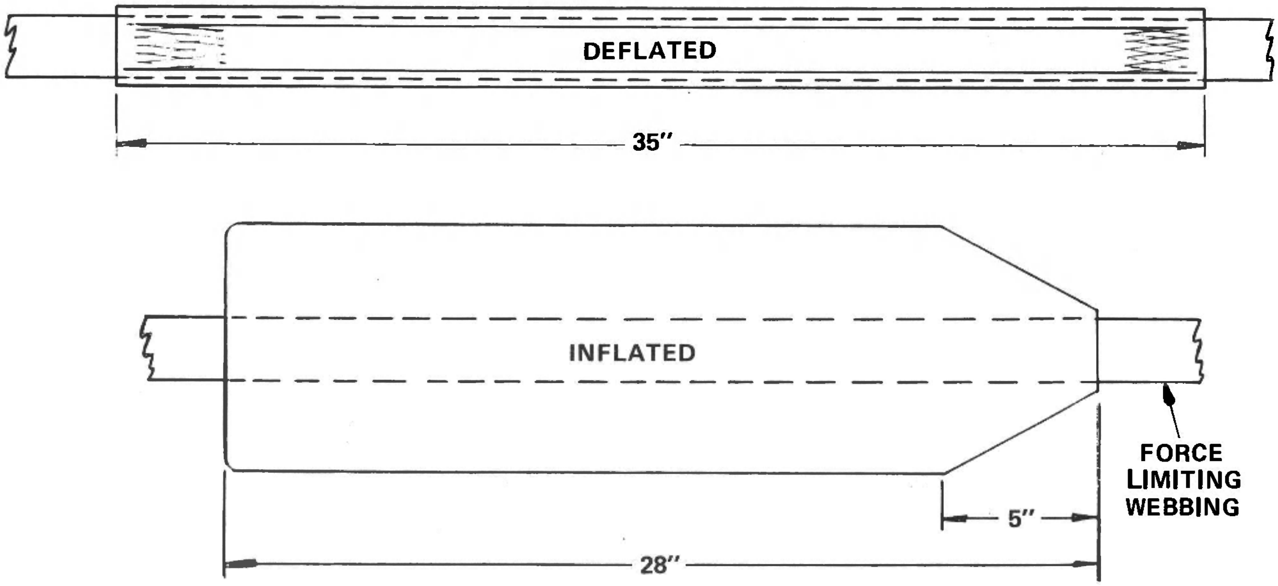


Figure 17b FINAL PHASE III AIR BELT DESIGN

Analysis of films of this run indicated that as a result of retractor spooloff (no web clamp), the upper portion of the air belt moved with the occupant. For the passenger with the web clamp, the end of the inflatable belt remained fixed. However, the passenger slid along the belt, since the belt reoriented itself with respect to the occupant torso by moving up the torso and closer to the arm pit.

The net result, for this configuration, was that both the occupants translated forward in an identical manner with or without the web clamp. Head and chest acceleration responses were also similar. Chest criteria were not satisfied in either case because the available Takata webbing force limiting stroke was exceeded. At the conclusion of this run, it was decided to delete use of the web clamp since (1) for this application it was not reducing occupant forward motion and (2) two failures had occurred in which the web clamp severed the webbing.

During the next four sled tests (Run 1844 through 1847) the upper roof rail effective anchor point (roller or D ring) was moved rearward as a means of increasing the Takata force limiting webbing available for stroking.

Increasing the available load limiting webbing length by routing the webbing through a roof rail D ring moved six inches rearward from the original position of the web clamp proved effective in limiting the chest response to acceptable levels. The next area to receive attention was occupant/occupant head contact which occurred at the beginning of rebound.

In order to alter the dummy kinematics, the webbing was routed through a D ring fixed to the B pillar in sled Runs 1862-1866. Head contact was then either eliminated or occurred late in the rebound period. However, this new line of action for the air belt resulted in increased occupant displacements. Sled Runs 1862 through 1866 were performed with varying lengths of webbing remaining on the retractor spool. Figure 18 displays the observed spooloff as a function of webbing length left on the retractor at a belt

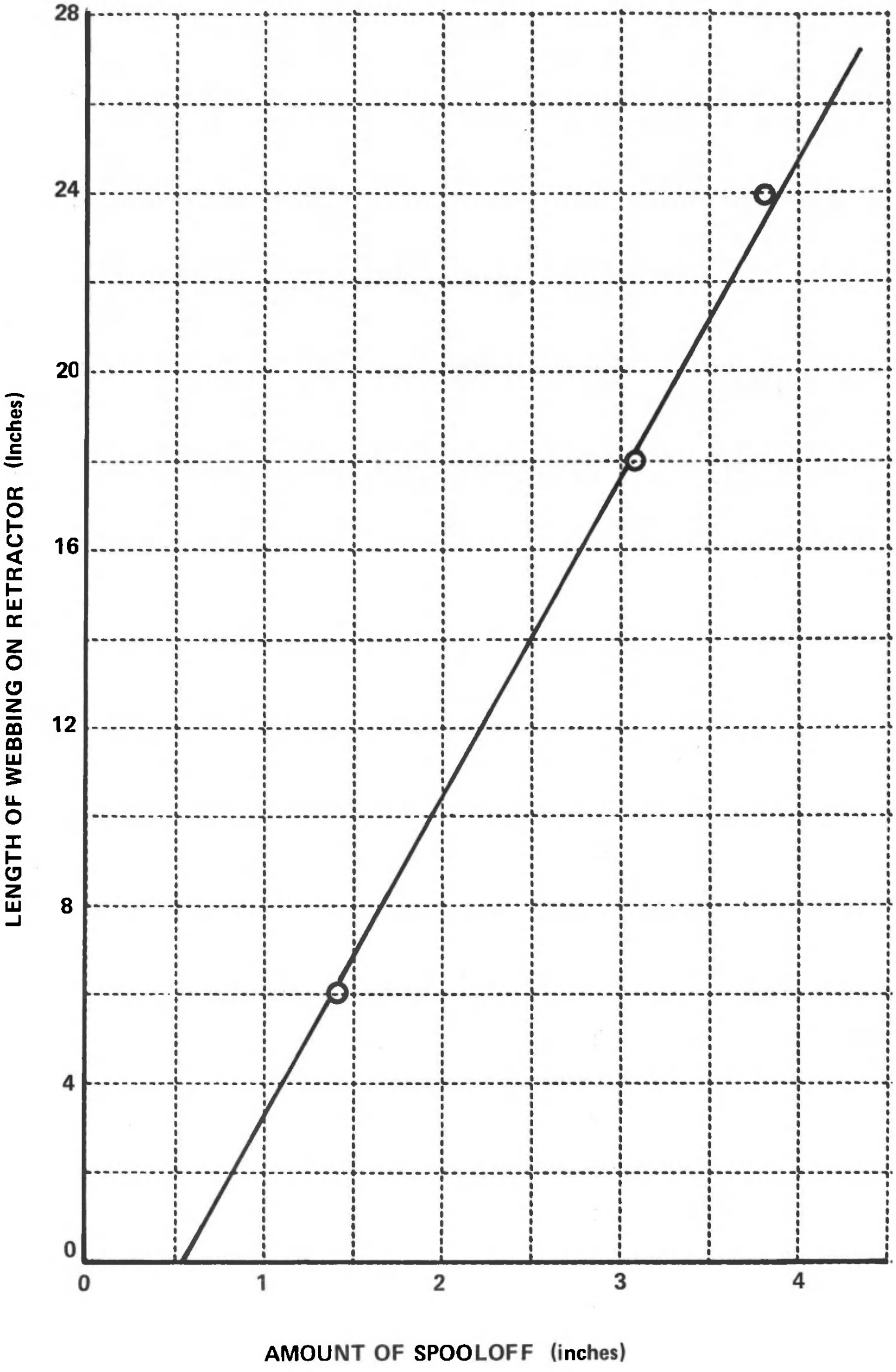

28
24
20
16
12
8
4
0
LENGTH OF WEBBING ON RETRACTOR (Inches)
0
1
2
3
4
AMOUNT OF SPOOLOFF (inches)

Figure 18

force level of 600 pounds. Almost four inches of spooloff occurred with 24 inches of retracted webbing as compared to less than 1.5 inches of spooloff with six inches of spooled belt.

Occupant head contact with the instrument panel did not occur when 18 inches or less of Takata webbing remained retracted on the spool. However, when 24 inches of webbing were left on the spool, head/dash contact resulted (compare sled Runs 1862, 1863, 1865 and 1866 with Run 1864).

Acceptable 50th percentile male passenger head, chest, and femur performance was achieved at 46 mph with 18 inches of retracted webbing (Runs 1865 and 1866). Corresponding driver chest and femur responses were also satisfactory. The head results were unacceptable. It should be noted, however, that driver head responses were acceptable with 6 and 24 inches of spooled webbing (Runs 1863 and 1864).

Eighteen inches of webbing are required on the retractor spool for operation of the passive mechanism. As such, that constituted the final geometry. Since both driver and passenger chest responses were close to the 60 g limit, it was concluded that 46 mph sled performance was marginally achievable for 50th percentile dummies in this final configuration.

The last two sled tests (Run 1868 and 1869) were 5th percentile female size and 95th percentile male size dummy tests at 41.4 mph. Acceptable chest performance was observed for the 95th percentile occupant in both the driver and passenger positions. Head responses were slightly high due to head/windshield contact. Satisfactory performance at 40 mph for the 95th male appeared achievable for both front seat occupant positions.

The 5th percentile female dummy results were poor in both the driver and passenger positions at 41.4 mph. As the female dummy translated forward, the upper part of the inflatable portion of the air belt rode up and reacted the dummy's head. It appeared that a variable B pillar D ring position was required to lower the initial position of the air belt.

Continued effort to analyze the effectiveness of the restraint system with regard to occupant size, in particular the 5th percentile female, was not expended during the developmental test series. Additional tests were performed during the validation test series.

4.3 Final System Configuration

Figure 19 depicts the final system layout arrived at through developmental testing.

Force limiting webbing is played out from the retractor through a rearward located roof rail D ring. From this point, the webbing travels forward to a D ring mounted on the B pillar. The track for passive belt operation goes from the A pillar along the roof rail to the B pillar and down the B pillar to the location of the D ring in Figure 19 (50th and 95th percentile male position). This is the same location as the upper torso belt anchor position in the base vehicle. The inflatable portion of the air belt commences slightly forward of the B pillar. The tubing from the inflator manifold is inserted at the inboard end of the air belt. Webbing, sewn to the inboard end of the inflatable belt, is routed through a seat frame mounted D ring to the floorboard anchor point.

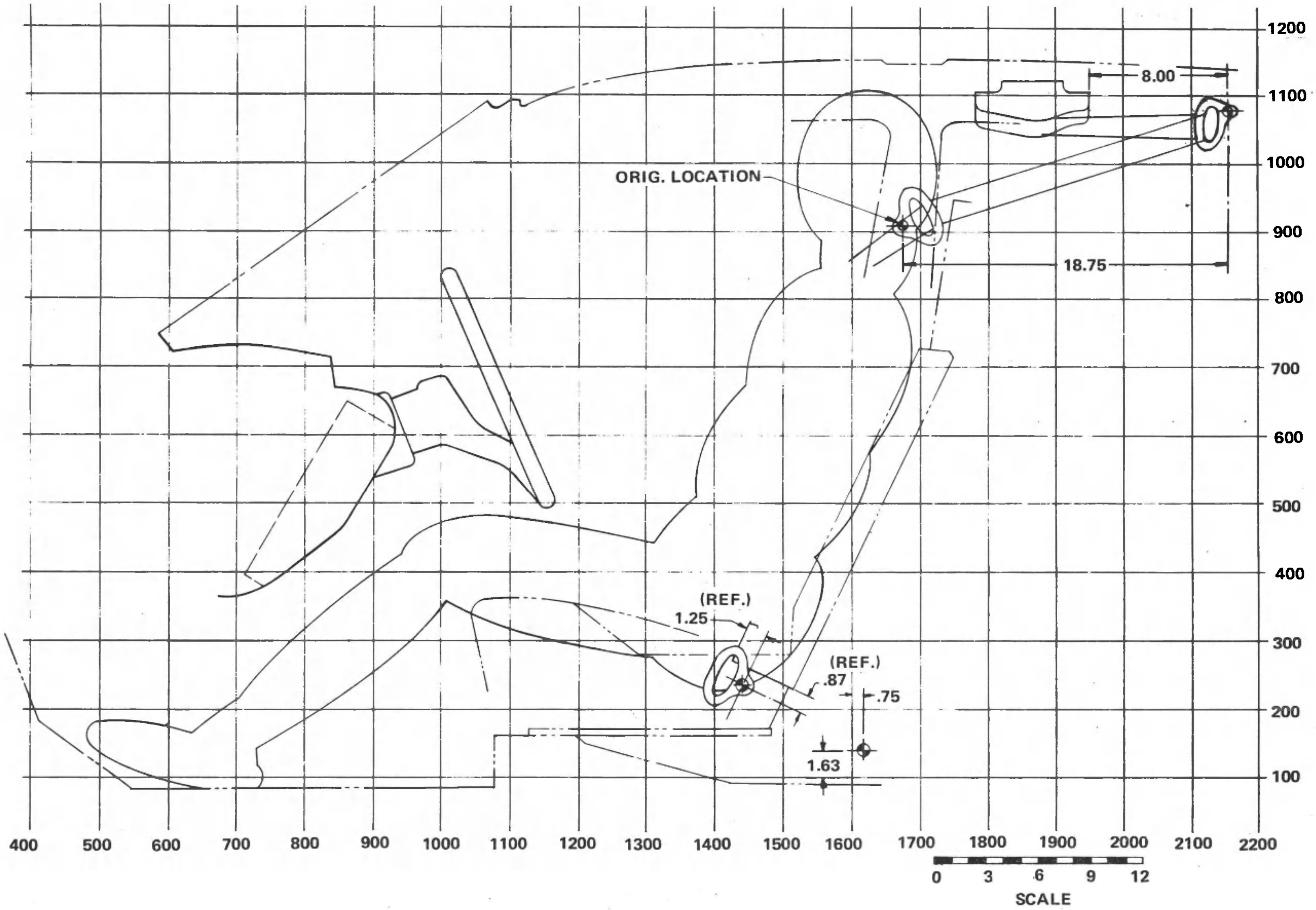


Figure 19 RSV AIR BELT ANCHOR POINT GEOMETRY

5.0 RSV VALIDATION SLED TESTING

Twenty-five sled runs were conducted as part of the validation testing of the air belt restraint system. Eleven of these tests were one occupant demonstrations. These sled runs were performed with an appropriately down-sized inflator. Tank tests at Thiokol indicated that a downloaded inflator with 65 grams of propellant would provide half of the gas volume of the 110 gram unit used with two air belts. The inflator housing did not change; and therefore a common manifold, with removeable plugs on the port nozzles, was used for both one and two air belt systems. The single air belt exposures were obtained coincident with RSV rear seat occupant and driver air bag testing.

Variables examined during the validation testing included occupant size, sled speed, seat positioning, lap belt use, and sled angle. Data for 39 occupant exposures were generated. Limited testing was conducted with the 5th percentile female and 95th percentile male dummies. Emphasis was placed upon 50th percentile male size dummy performance.

For these validation tests, final design components were used exclusively, i.e., the air belt restraint system, Takata lap belt retractors and webbing, Phase IV seats, and Phase IV instrument panels. (With the exception that in the angle impact simulations, developmental sled test knee restraints were used.) Foam padding was also installed along the A pillars, B pillars, and roof rail of the sled buck.

Lastly, further analysis indicated that the squib fire time should be reduced to 8 milliseconds (from 13 millisecond value used in developmental sled testing) because the RSV sled pulse did not simulate the initial soft bumper portion of the RSV vehicle pulse. This can be seen in Figures 20 and 21 where deceleration-time and deceleration-displacement curves have been plotted for the sled pulse and simulated Phase III structure.

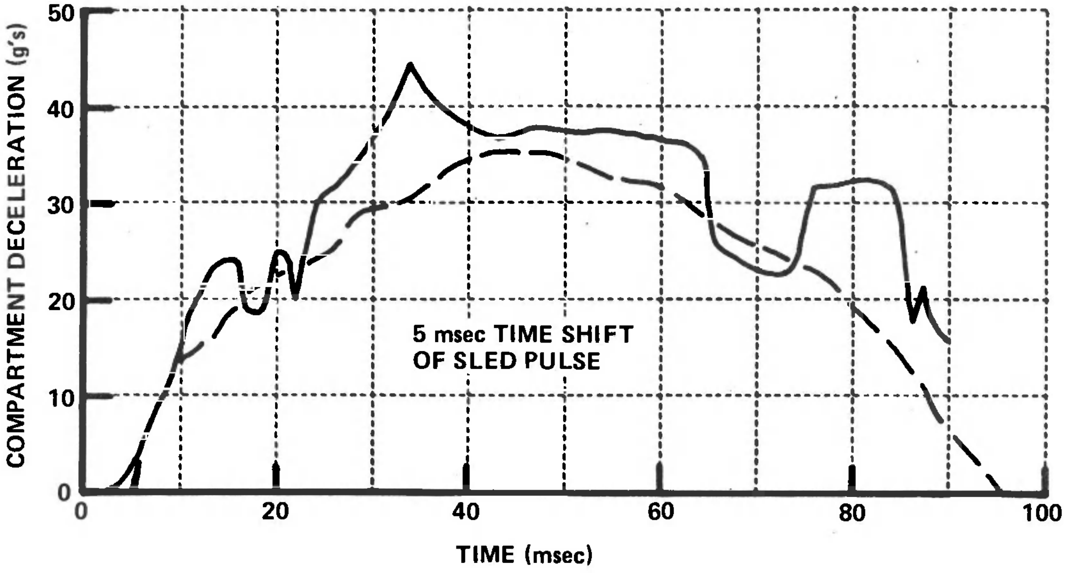


Figure 20 DECELERATION-TIME COMPARISON OF SLED & SIMULATED PHASE III STRUCTURAL PULSES

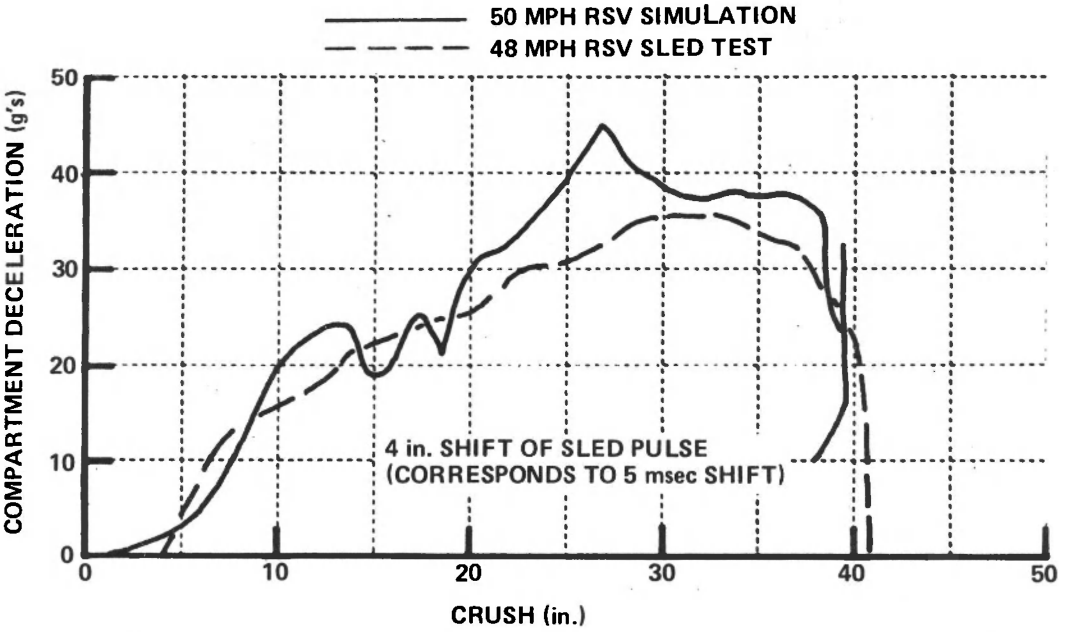


Figure 21 DECELERATION-DISPLACEMENT COMPARISON OF SLED & SIMULATED PHASE III STRUCTURAL PULSES

Results for the validation sled tests have been summarized in Tables 4, 5, 6 and 7. Discussions reviewing these results are presented in the ensuing subsections.

5.1 Fifth Percentile Female Dummy Results

In developmental sled tests with the 5th percentile female dummy, kinematics were poor. The orientation of the air belt with respect to the dummy torso was such that, when deployed, there was too much head restraint. This resulted in the dummy head being forced into the seat back. In order to improve the load distribution of the air belt, the position of the B pillar D ring was lowered 2.5 inches for the validation sled tests with the female dummy. This adjustment would have to be incorporated into the passive track mechanism. Furthermore, the sled test speed was reduced to 35 mph, (the two developmental tests were performed at 41.4 mph).

Three validation sled tests were conducted. There were two passenger position exposures, Runs 1882 and 1885 (with and without lap belts), and one driver exposure, Run 1884. Data from these tests are summarized in Tables 4 and 5 respectively. HIC numbers and chest resultant accelerations are also graphically displayed in Figures 22 and 23.

In the first sled test (Run 1882), the female dummy submarined even though the knees were engaged by the honeycomb restraint. Again the air belt rode up the torso and reacted the face. Excessive rearward head rotation resulted. An eight shot Polaroid sequence picture of the test event is displayed in Figure 24.

In the subsequent passenger female dummy test, Run 1885, a load limiting Takata lap belt was employed (620 pounds). The lap belt reduced the submarining tendency by reducing hip travel. The head results were dramatically improved, and film results revealed acceptable kinematics. However, the chest resultant acceleration was an unacceptable 81 g's as compared to 59 g's in sled Test 1882. Polaroid sequence pictures of this test are presented in Figure 25.

Table 4

RSV PERFORMANCE VALIDATION
SINGLE AIRBELT WITH DOWNSIZED INFLATOR
SLED TEST RESULTS

TEST CONDITIONS						RESTRAINT CONDITIONS		DUMMY		DUMMY DATA								RESTRAINT DATA							
										HEAD			CHEST		PELVIS	FEMUR LOAD, lbs		KNEE BAR PENETRATION							
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.		LAP BELT	SIZE	POSITION	H_R (g's)	HSI	HIC	C_R (g's)	CSI	P_x (g's)	L	R	L (in.)	R (in.)	AIR BELT PRESSURE (psig)	UPPER BELT LOAD (lb.)	UPPER BELT ELONGATION (in.)	LAP BELT LOAD (lb.)	LAP BELT ELONGATION (in.)	
10/20	1881	39.9	30.5	35.0			NO	50%	PASSENGER MID	47	550	467	48	490	64	500	1200	3-3/4	4-1/8	*	1800	2.0	–	–	(1)
10/21	1882	35.0	27.9	27.2		B PILLAR D RING DOWN 2.5"	NO	5%	PASSENGER FORWARD	94	2000+	1669	59	800		450	500	3-3/8	2-3/4	19.0	1450	1.0	–	–	
10/24	1883	40.2	29.9	35.0			NO	95%	PASSENGER REAR	57 (80)	700 (1380)	846	44	470	48	1350	1600	6-3/4	6-7/8	19.5	2100	3.25	–	–	
10/27	1885	34.6	27.1	26.9		B PILLAR D RING DOWN 2.5"	YES	5th	PASSENGER FORWARD	52 (112)	760 (1590)	1126	81	1000		650	500	2-3/4	1-5/8	*	1900	0	620	.38	(1)
11/1	1887	35.0	27.6	26.7			NO	95th	PASSENGER REAR	64	660	528	43	360	52	250	1420	–	–	20	1900	–	–	–	
11/1	1888	35.1	27.7	27.2			NO	95th	DRIVER REAR	108	920	524	44	420	80	1400	1500	3.5	2.0	17.5	1880	2.2	–	–	
11/2	1889	40.3	29.9	35.6			NO	95th	DRIVER REAR	100	1270	860	53	540	96	2250	2200	3.5	3.2	20.5	1960	2.5	–	–	
11/2	1890	40.3	30.3	35.3			YES	95th	DRIVER REAR	83	1400	1116	50	500	–	1150	1050	2.5	1.8	16.5	2080	2.5	800	2.2	
11/3	1891	40.2	29.6	35.4			YES	95th	PASSENGER REAR	106	1100	871	48	500	52	300	800	3.5	3.8	20.5	2080	3.0	930	4.8	

(1) AIR BELT PRESSURE NOT AVAILABLE.

Table 5

RSV PERFORMANCE VALIDATION
AIRBELT
SLED TEST RESULTS

TEST CONDITIONS						RESTRAINT CONDITIONS		DUMMY		DUMMY DATA								RESTRAINT DATA							
										HEAD			CHEST		PELVIS	FEMUR LOAD, lbs		KNEE BAR PENETRATION							
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.		LAP BELT	SIZE	POSITION	H_R (g's)	HSI	HIC	C_R (g's)	CSI	P_x (g's)	L	R	L (in.)	R (in.)	AIR BELT PRESSURE (psig)	UPPER BELT LOAD (lb.)	UPPER BELT ELONGATION (in.)	LAP BELT LOAD (lb.)	LAP BELT ELONGATION (in.)	
10/26	1884	35.0	28.2	27.0		8 PILLAR D RING DOWN 2.5"	NO	5%	DRIVER (FORWARD)	100	2000+	2151	67	1000		1250	50	1-3/4	2-1/4	21.0	1640	0.75	–	–	
							NO	95%	PASS (REAR)	46	600	627	39	300	48	1050	2060	6-7/8	6-7/8	21.5	1800	2.50	–	–	
11/16	1900	34.9	28.2	27.0			NO	50%	DRIVER (MID)	56	810	561	38	410	56	1600	850	3.7	3.7	18.3	1770	0.5	–	–	
							NO	50%	PASS (MID)	56	550	393	50	400	48	730	1070	3.5	3.2	19.5	1640	0.5	–	–	
11/17	1901	39.9	29.4	35.2			NO	50th	DRIVER (MID)	62	920	641	48	520	66	1800	950	4.5	4	14.0	1660	0.3	–	–	
							NO	50th	PASS (MID)	48	610	513	47	470	56	1120	1200	6	4	21.5	1800	0.5	–	–	
11/18	1902	44.5	34.4	36.2			NO	50th	DRIVER (MID)	90	960	688	58	720	72	1750	980	5.2	5.2	16.8	1880	1.4	–	–	(1)
							NO	50th	PASS (MID)	59 (141)	900 (1500)	925	52	610	67	1350	1800	6.5	5.2	24.5	1800	1.3	–	–	(2)

(1) SEAM FAILURE ON DRIVER BAG.

(2) PASSENGER SUBMARINED – INSUFFICIENT I.P. AND SEAT RESTRAINT.

Table 5 (Cont.)

RSV PERFORMANCE VALIDATION
AIRBELT
SLED TEST RESULTS

TEST CDNOITIDNS						RESTRAINT CONDITIONS		DUMMY		DUMMY DATA								RESTRAINT DATA							
										HEAD			CHEST		PELVIS	FEMUR LOAD, lbs		KNEE BAR PENETRATION							
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.		LAP BELT	SIZE	POSITION	H_R (g's)	HSI	HIC	C_R (g's)	CSI	P_x (g's)	L	R	L (in.)	R (in.)	AIR BELT PRESSURE (psig)	UPPER BELT LOAD (lb.)	UPPER BELT ELONGATION (in.)	LAP BELT LOAD (lb.)	LAP BELT ELONGATION (in.)	
11/22	1903	45.1	35.4	36.5		NEW SEAT,IP	NO	50th	DRIVER (MID)	68	970	646	54	760	85	1320	1120	3.4	3.2	19.8	1860	1.5	–	–	(1)
							NO	50th	PASS. (MID)	55	920	677	50	570	68	800	1350	4.0	3.7	25.5	1760	1.0	–	–	
11/23	1904	45.2	35.4	36.7		BOILER PLATE DASH	NO	50th	DRIVER (MID)	93	1320	892	67	880	74	2200	2050	2.7	2.0	21.0	2150	2.0	–	–	
							NO	50th	PASS (MID)	55	1000	687	55	550	70	2050	2150	2.2	2.5	22.0	2050	2.0	–	–	
11/28	1905	45.2	36.7	36.6		MODIFIED DASH	NO	50th	DRIVER (MID)	172	2000+	1555	55	780	88	1450	900	2.7	3.0		1525	0	–	–	(2)
							NO	50th	PASS (MID)	58	920	651	55	775	96	750	1500	4.2	4.2	28.0	1880	1.25	–	–	
12/1	1906	45.1	35.8	36.6			NO	50th	DRIVER (MID)	55	850	636	54	720	94	1700	1000	4.5	4.5	20.7	1850	2.25	–	–	
							NO	50th	PASS (MID)	65	920	654	58	660	88	980	1600	7.0	5.5	24.0	2250	2.0	–	–	

(1) SEAM TEAR OF DRIVER BAG

(2) WEBBING SEPARATED FROM TOP OF DRIVER BAG

Table 5 (Cont.)

RSV PERFORMANCE VALIDATION
AIRBELT
SLED TEST RESULTS

TEST CONDITIONS						RESTRAINT CONDITIONS		DUMMY		DUMMY DATA								RESTRAINT DATA							
										HEAD			CHEST		PELVIS	FEMUR LOAD, lbs		KNEE BAR PENETRATION							
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.		LAP BELT	SIZE	POSITION	H_R (g's)	HSI	HIC	C_R (g's)	CSI	P_x (g's)	L	R	L (in.)	R (in.)	AIR BELT PRESSURE (psig)	UPPER BELT LOAD (lb.)	UPPER BELT ELONGATION (in.)	LAP BELT LOAD (lb.)	LAP BELT ELONGATION (in.)	
12/2	1907	45.1	36.6	36.8			YES	50th	DRIVER (MID)	96	1240	966	60	800	72	1420	1000	3.0	3.2	18.3	2000	1.7	680	2.7	
							YES	50th	PASS (MID)	73	920	688	65	780	90	770	700	4.0	3.5	24.5	2000	1.4	680	1.5	(1)
12/6	1908	45.2	35.7	36.8			NO	50th	DRIVER (FORWARD)	61	920	625	70	920	72	1850	850	3.2	3.5	19.6	2000	2.2	–	–	
							NO	50th	PASS (FORWARD)	56	980	627	51	700	84	1120	1550	7.0	6.2	20.7	1960	1.6	–	–	
12/7	1909	45.1	35.7	36.7			NO	50th	DRIVER (REAR)	100	1500	1117	64	840	72	1550	1250	4.5	4.5	20.5	2200	2.0	–	–	(2)
							NO	50th	PASS (REAR)	51 (100)	1000 (1750)	1146	49	770	60	1150	1770	7.5	7.0	28.0	2000	2.0	–	–	

(1) SEAT CUSHION FRAME FAILURE RESULTED IN HIGH C_Z COMPONENT
(2) SEAM TEAR ON DRIVER BAG

Table 6

RSV PERFORMANCE VALIDATION
AIRBELT
ANGLED SLED TEST RESULTS

TEST CONDITIONS						RESTRAINT CONDITIONS		DUMMY		DUMMY DATA								RESTRAINT DATA						
										HEAD			CHEST		PELVIS	FEMUR LOAD, lbs		KNEE BAR PENETRATION						
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.		LAP BELT	SIZE	POSITION	H_R (g's)	HSI	HIC	C_R (g's)	CSI	P_x (g's)	L	R	L (in.)	R (in.)	AIR BELT PRESSURE (psig)	UPPER BELT LOAD (lb.)	UPPER BELT ELONGATION (in.)	LAP BELT LOAD (lb.)	LAP BELT ELONGATION (in.)
12/19	1913	44.8	26.8	54.3	+12°		NO	50th	DRIVER (MID)	48	570	485	43	420	69	1430	1900	1.5	2.0	19.0	1680	0.9	–	–
							NO	50th	PASS (MID)	44	440	347	38	330	70	1820	1570	2.2	1.7	18.0	1730	0.9	–	–
12/20	1914	45.0	26.1	53.4	-12°		NO	50th	DRIVER (MID)	33	320	266	44	370	66	1550	1740	1.1	1.2	17.4	1820	2.0	–	–
							NO	50th	PASS (MID)	48	540	453	40	400	60	1450	1750	1.2	1.5	18.7	1760	2.0	–	–
12/23	1917	44.9	25.8	54.1	2 DRIVERS -20° ANGL		NO	50th	DRIVER (RIGHT)	56	540	512	44	480	76	2180	1750	1.7	1.5	19.3	1730	0.0	–	–
							NO	50th	DRIVER (LEFT)	52	650	359	45	520	72	1550	1750	2.1	2.1	20.0	1570	0.0	–	

Table 7

RSV PERFORMANCE VALIDATION
SINGLE AIRBELT WITH DOWNSIZED INFLATOR
ANGLED SLED TEST RESULTS

TEST CONDITIONS						RESTRAINT CONDITIONS		DUMMY		DUMMY DATA								RESTRAINT DATA						
										HEAD			CHEST		PELVIS	FEMUR LOAD, lbs		KNEE BAR PENETRATION						
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.		LAP BELT	SIZE	POSITION	H_R (g's)	HSI	HIC	C_R (g's)	CSI	P_x (g's)	L	R	L (in.)	R (in.)	AIR BELT PRESSURE (psig)	UPPER BELT LOAD (lb.)	UPPER BELT ELONGATION (in.)	LAP BELT LOAD (lb.)	LAP BELT ELONGATION (in.)
12/21	19 15	45.1	26.3	55.0	+20°		NO	50th	PASS (MID)	52	550	412	36	310	60	1470	1750	2.0	1.7	18.5	1600	1.0	–	–
12/22	19 16	45.1	25.9	55.1	-20°		NO	50th	PASS (MID)	63	660	540	53	600	65	1680	1730	2.1	2.0	17.5	1700	0.4	–	–

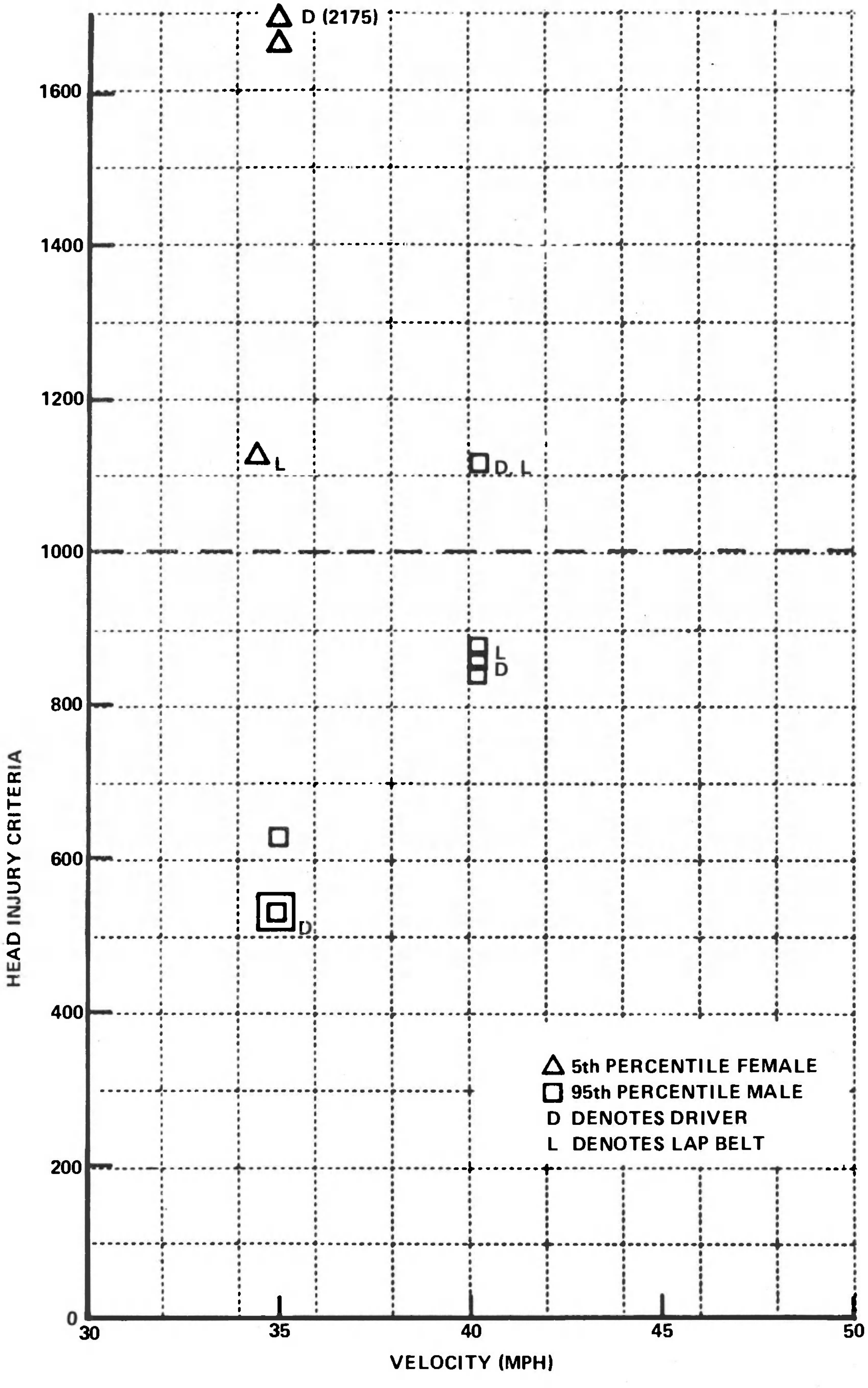


Figure 22 AIR BELT VALIDATION; SLED TEST RESULTS (5th PERCENTILE FEMALE, 95th PERCENTILE MALE)

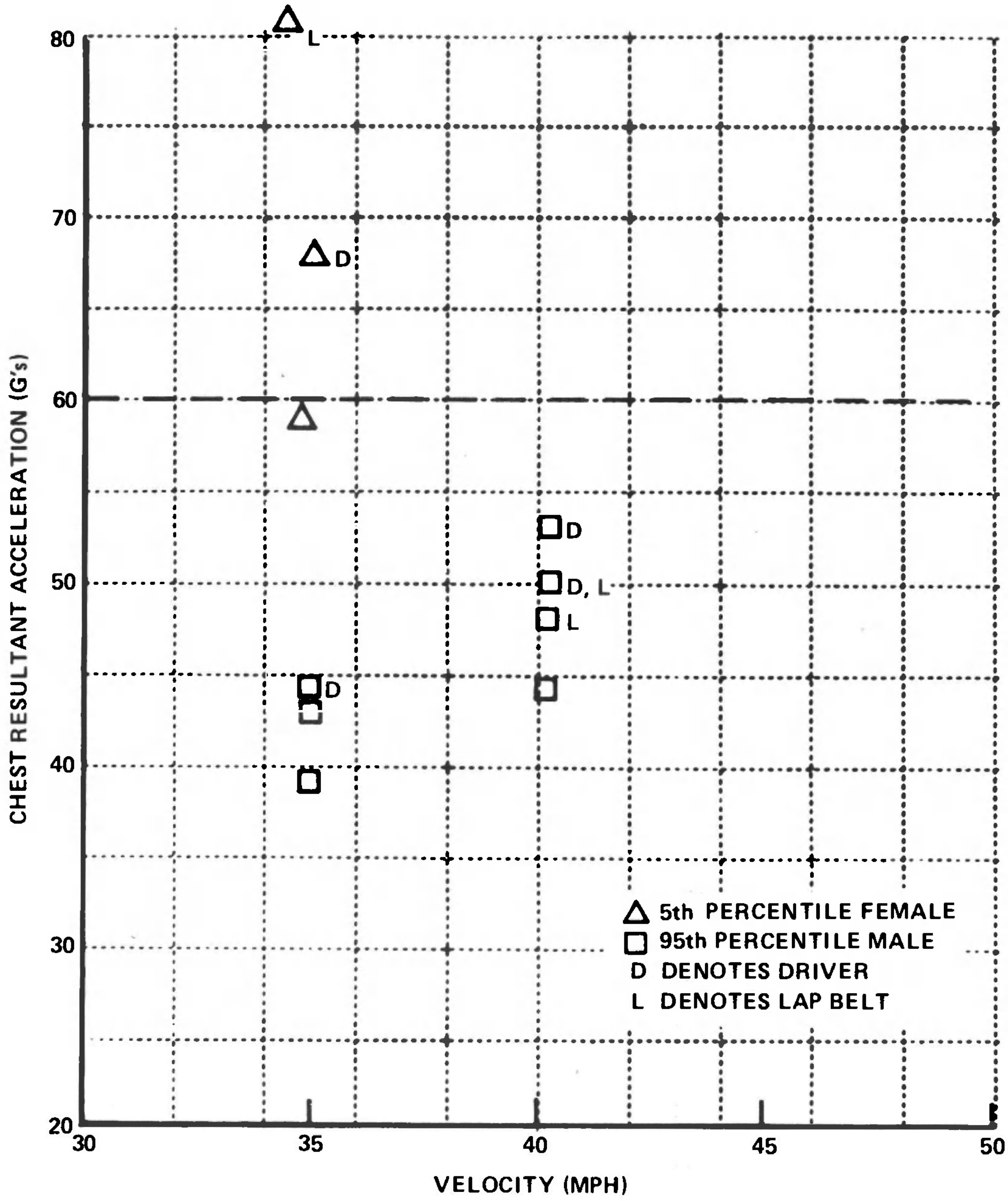


Figure 23 AIR BELT VALIDATION; SLED TEST RESULTS (5th PERCENTILE FEMALE; 95th PERCENTILE MALE)

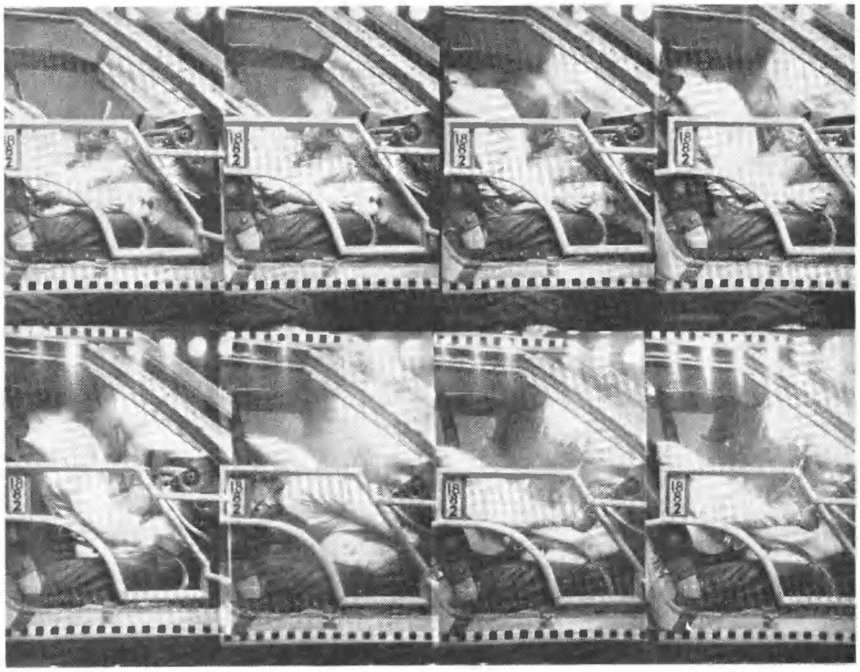


Figure 24 5th PERCENTILE FEMALE KINEMATICS AT 35 MPH

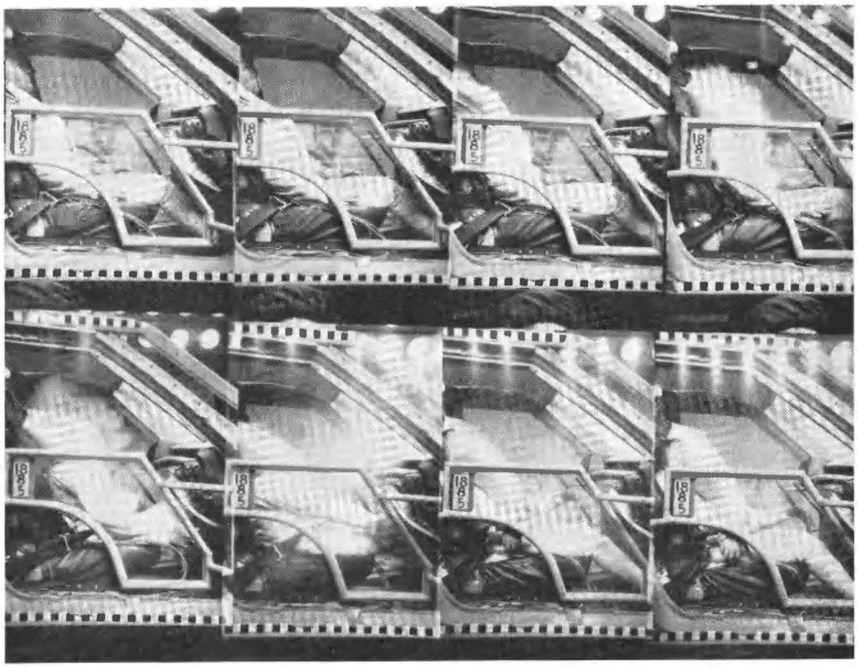


Figure 25 5th PERCENTILE FEMALE RESULTS WITH A LOAD LIMITING LAP BELT AT 35 MPH

One test was performed with the 5th percentile female dummy in the driver position (Run 1884). Kinematics and the injury criteria were both unacceptable.

Based upon these very limited test results for the 5th percentile dummy, it appears that a reduction in hip travel is necessary to achieve acceptable kinematics. Potential solutions are:

- Use of a structural seat pan to provide resistance to plowing (forward travel of the hips) by the occupant. The seat used in the VW passive belt Rabbit may be acceptable for this purpose.
- Reducing the clearance between the knees and the knee restraint (presently ~ 4 inches).

Chest accelerations must also be reduced. This can be accomplished by:

- lowering the force level of the air belt load limiting Takata webbing to 1200-1500 pounds.

5.2 95th Percentile Male Dummy Results

Seven validation sled tests were conducted with the 95th percentile male dummy. Data for two passenger and one driver exposure were obtained at 35 mph (Runs 1884, 1887, and 1888). The remaining four tests were performed at 40 mph (Runs 1883, 1889, 1890 and 1891). These latter tests evaluated driver and passenger 95th percentile dummy performance with and without lap belts. Results of these sled runs have been summarized in Tables 4 and 5. HIC numbers and chest resultant accelerations are also graphically displayed in Figures 22 and 23.

Acceptable results for head, chest and femur injury indices were attained in all of these demonstrations except for the case of the lap belted driver at 40.3 mph (Run 1890). In that case, the HIC number just exceeded the limit at 1116. Kinematics were acceptable. Polaroid sequence pictures of Run 1890 are presented in Figure 26. For the other three 40 mph tests, the HIC numbers were all less than 900. Chest resultant accelerations were between 44 and 53 g's for all four 40 mph tests.

Thus, it is concluded that 40 mph performance can be demonstrated with the air belt restraint system for 95th percentile male occupants in both the driver and passenger seating positions. Acceptable results at 40 mph with a lap belt can be demonstrated for the passenger position. Satisfactory results in the 35 to 40 mph range are predicted for the lap belted driver.

5.3 50th Percentile Male Dummy Results

The most extensive validation testing was performed with the 50th percentile male size dummy. Sixteen sled tests were conducted resulting in twenty-nine occupant exposures. Performance sensitivities to speed, lap belt use, seat positioning, and sled angle were evaluated.

5.3.1 Speed Dependancy

Sled runs were conducted at 35, 40 and 45 mph with 50th percentile dummy drivers and passengers in the mid seat position. Results of these tests are summarized in Tables 4 and 5. HIC numbers and chest resultant accelerations are also graphically displayed in Figures 27-30. Acceptable results were attained throughout the speed range. For example, at 45 mph the driver and passenger dummy HIC numbers were both approximately 650 (four exposures). Chest resultant accelerations for both driver and passenger were also similar. Fifty-four g's were recorded for the one valid driver test (Run 1906) while values of 50, 55 and 58 g's were obtained for the passenger in Runs 1903, 1905 and 1906.

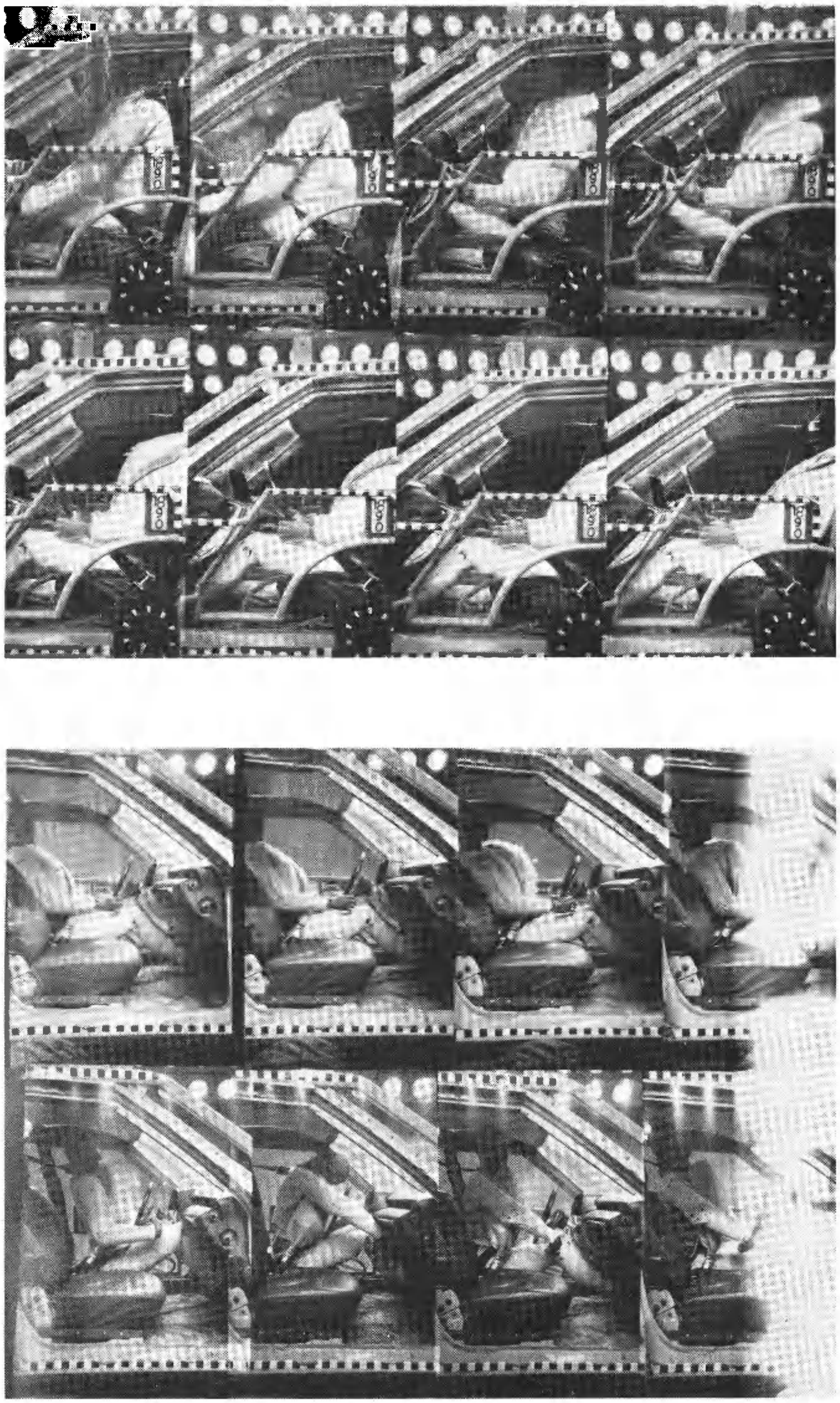


Figure 26 KINEMATICS OF 95th PERCENTILE MALE DUMMY WITH LAP BELT AT 40.3 MPH

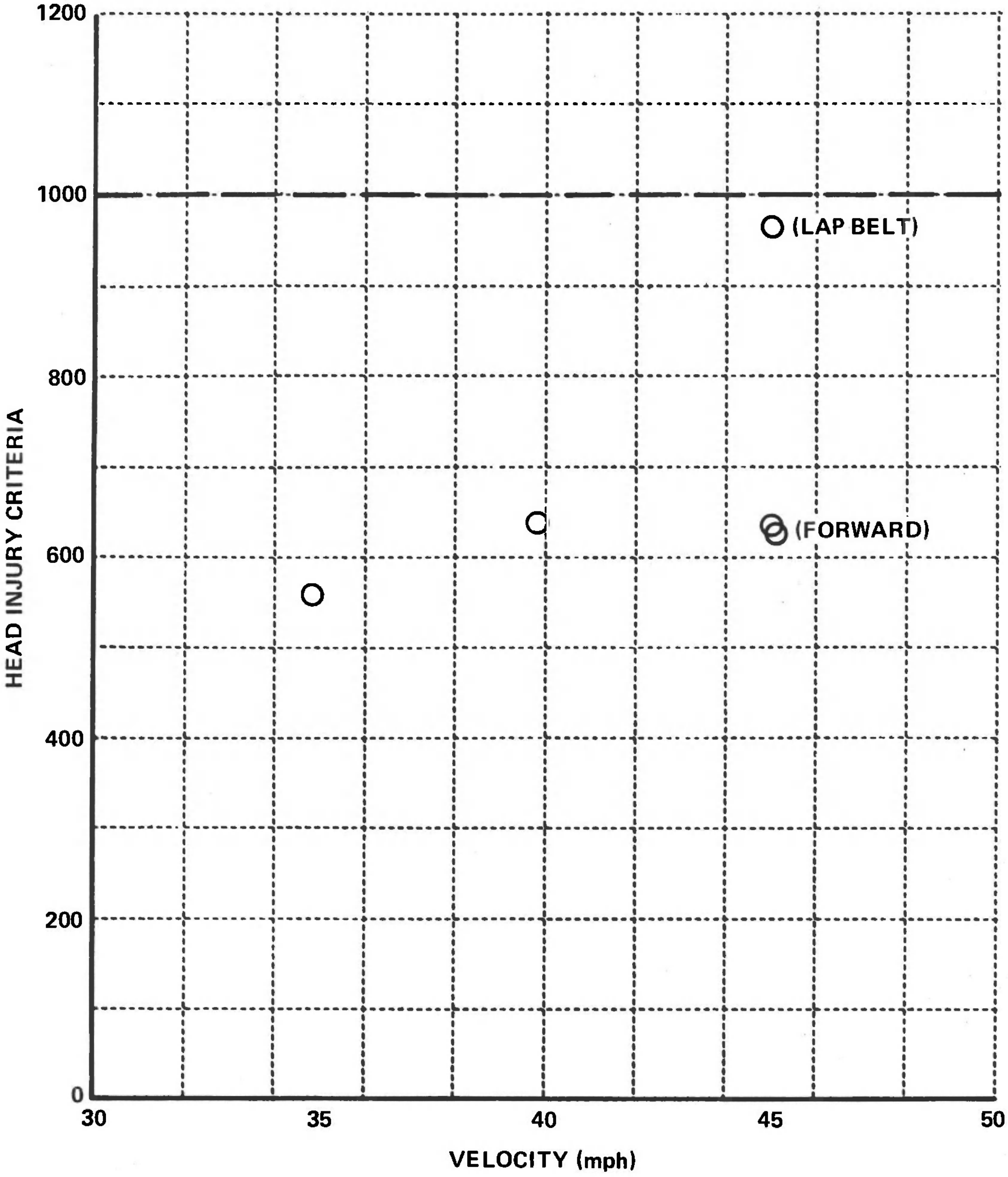


Figure 27 DRIVER AIRBELT VALIDATION; SLED TEST RESULTS (50th PERCENTILE MALE)

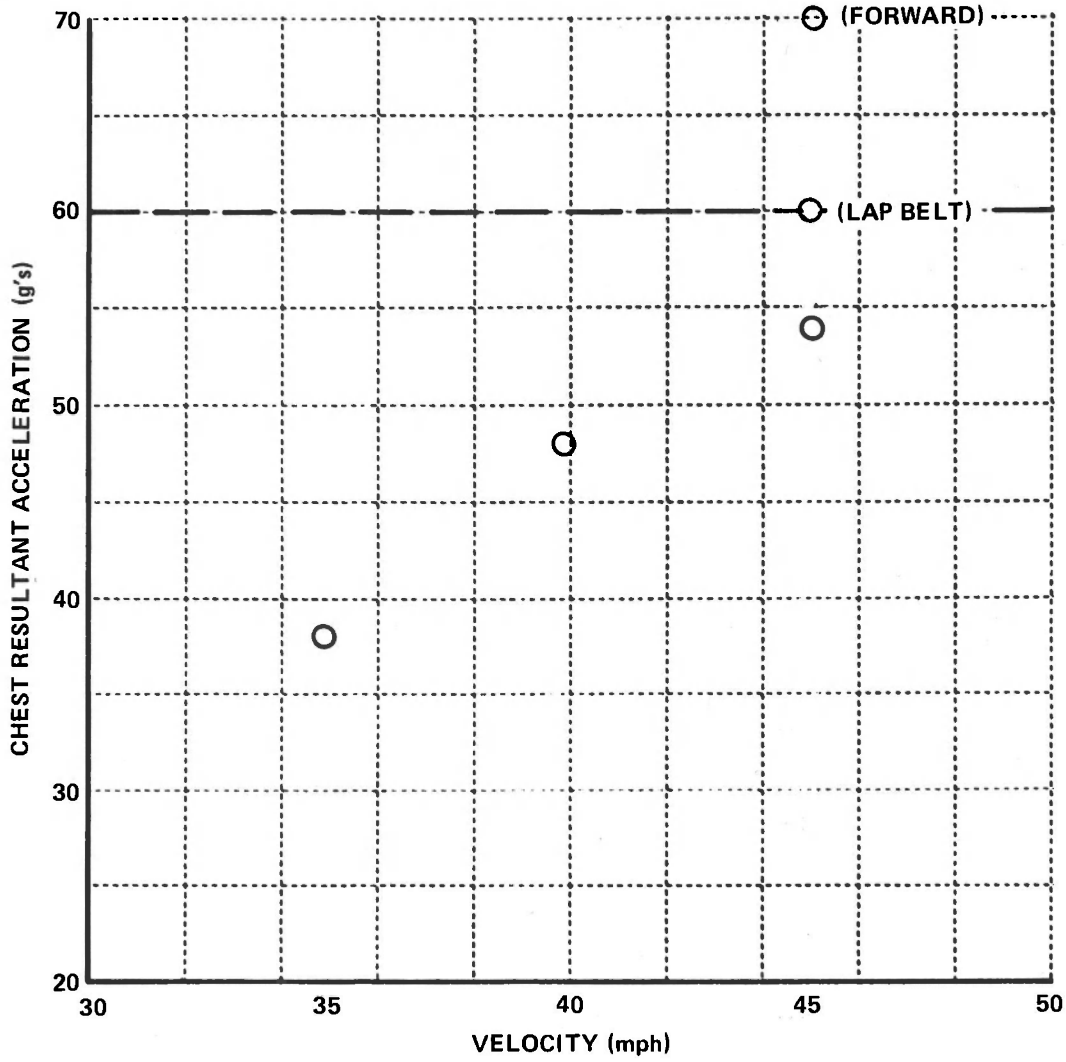


Figure 28 DRIVER AIRBELT VALIDATION; SLED TEST RESULTS (50th PERCENTILE MALE)

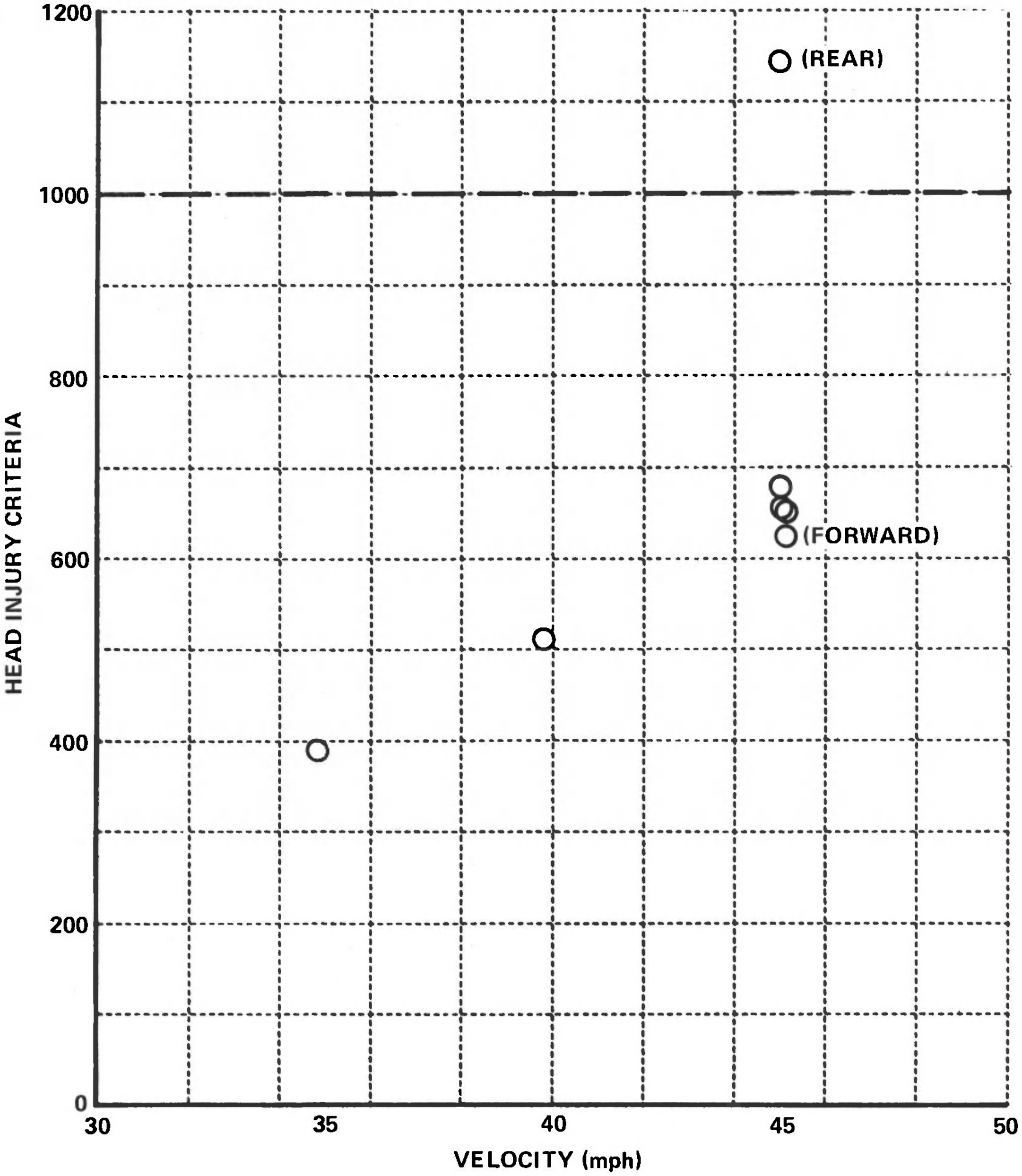


Figure 29 PASSENGER AIRBELT VALIDATION; SLED TEST RESULTS (50th PERCENTILE MALE)

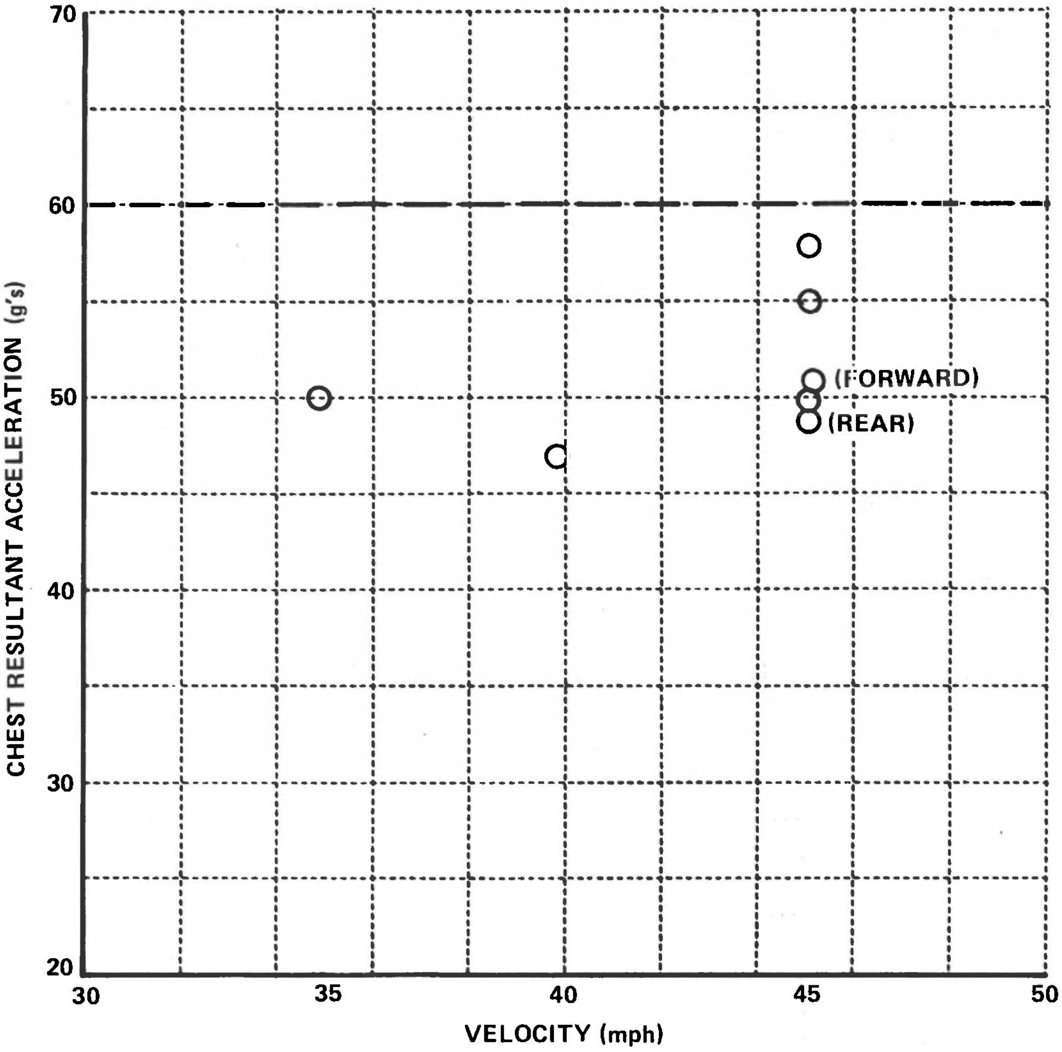


Figure 30 PASSENGER AIRBELT VALIDATION; SLED TEST RESULTS (50th PERCENTILE MALE)

5.3.2 Lap Belt Use

Sled Run 1907 was performed at 45.1 mph with lap belted 50th percentile dummies in the driver and passenger mid seat position. Both Takata lap belts yielded at 680 pounds. These data appear in Table 3 and in Figures 27 and 28. Satisfactory results were obtained for the driver position. The HIC number, 966, and the chest resultant acceleration, 60 g's, were both slightly higher than the unbelted case - Run 1906.

Valid results were not obtained for the passenger position dummy. The seat cushion frame tubing fractured during the test.

5.3.3 Seat Position

A measure of the dummy performance sensitivity with respect to the positioning of the front seats was also obtained as part of this validation test series. Sled Runs 1908 and 1909 were conducted at 45.2 and 45.1 mph with the front seats located in the full forward and full rear track positions. Data for these tests appear in Table 5 and in Figures 27-30. The allowable seat track travel in the RSV is five inches. Thus, these two tests examined the performance sensitivity of dummy positioning ±2.5 inches from the mid seat or baseline location.

For the full forward test, Run 1908, satisfactory results were obtained for the passenger position dummy. The HIC number was 627 while the chest resultant accelerations was 51 g's. Head results for the 50th percentile dummy driver were also acceptable; the HIC number was 625. However, the chest resultant, 70 g's, exceeded the limit due to torso/wheel contact.

In the full rear seat test, Run 1909, valid results were not obtained for the driver because a seam tear developed on that air belt. The passenger position dummy came off the seat resulting in a HIC number of 1146. The chest resultant acceleration for the passenger dummy was 49 g's.

In summary, the out-of-position seat tests indicate a problem in the full forward position for the driver due to wheel contact, and difficulty in retaining the passenger on the seat in the full rear test.

5.3.4 Angled Sled Tests

Upon conclusion of the aligned sled tests, five angled sled tests were performed with 50th percentile dummies in the mid seat position. Sled tests were performed with the buck rotated +12° and +20°. Provisions were made for the adaptation of a steering wheel on the passenger's side of the buck so that both plus and minus angles could be simulated with an actual sled rotation in only one direction. Developmental test knee restraints were used for the angled tests since the Phase IV instrument panels could not be readily modified to accept a steering column on the passenger side. Furthermore, the sled acceleration was modified to reflect the softer vehicle pulse which would be experienced in an angled impact. Figure 31 compares 45 mph sled pulses for an aligned (0°) and a 20° run. Lastly, a Phase IV door panel was used on the right hand side of the buck. An occupant in this seating position would translate towards the A pillar.

Excellent results were recorded at 45 mph test conditions for driver and passenger positions at both plus and minus sled angles. These data have been tabulated in Tables 6 and 7 and are graphically represented in Figures 32-35.

The highest recorded injury measures were for the case of the passenger translating towards the A pillar with the buck rotated 20°. The HIC number was 540 while the chest resultant acceleration was 53 g's.

The mild exposures experienced in these angled sled runs are a direct reflection of the milder sled pulse used. Lateral torso restraint provided by the RSV inner door panel also aided the dummy responses.

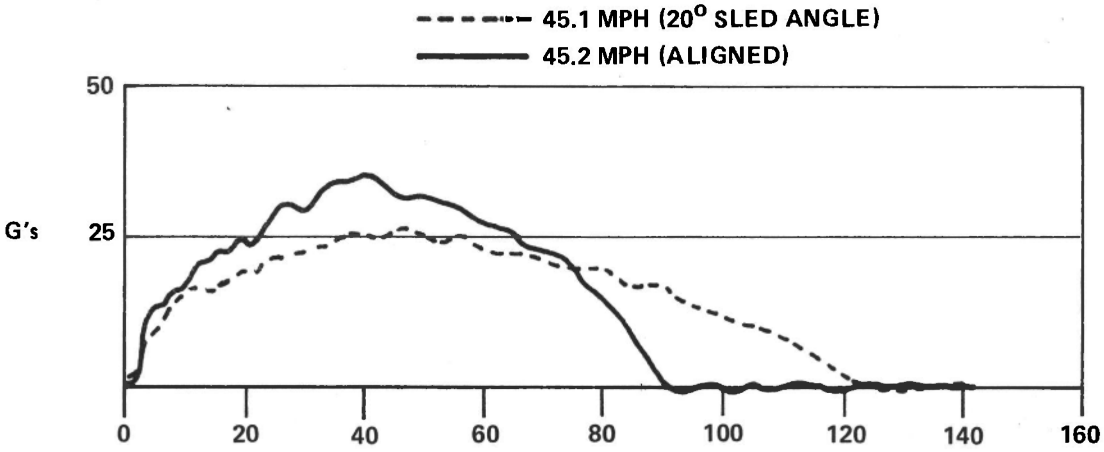


Figure 31 COMPARISON OF TYPICAL 45 MPH RSV SLED PULSES

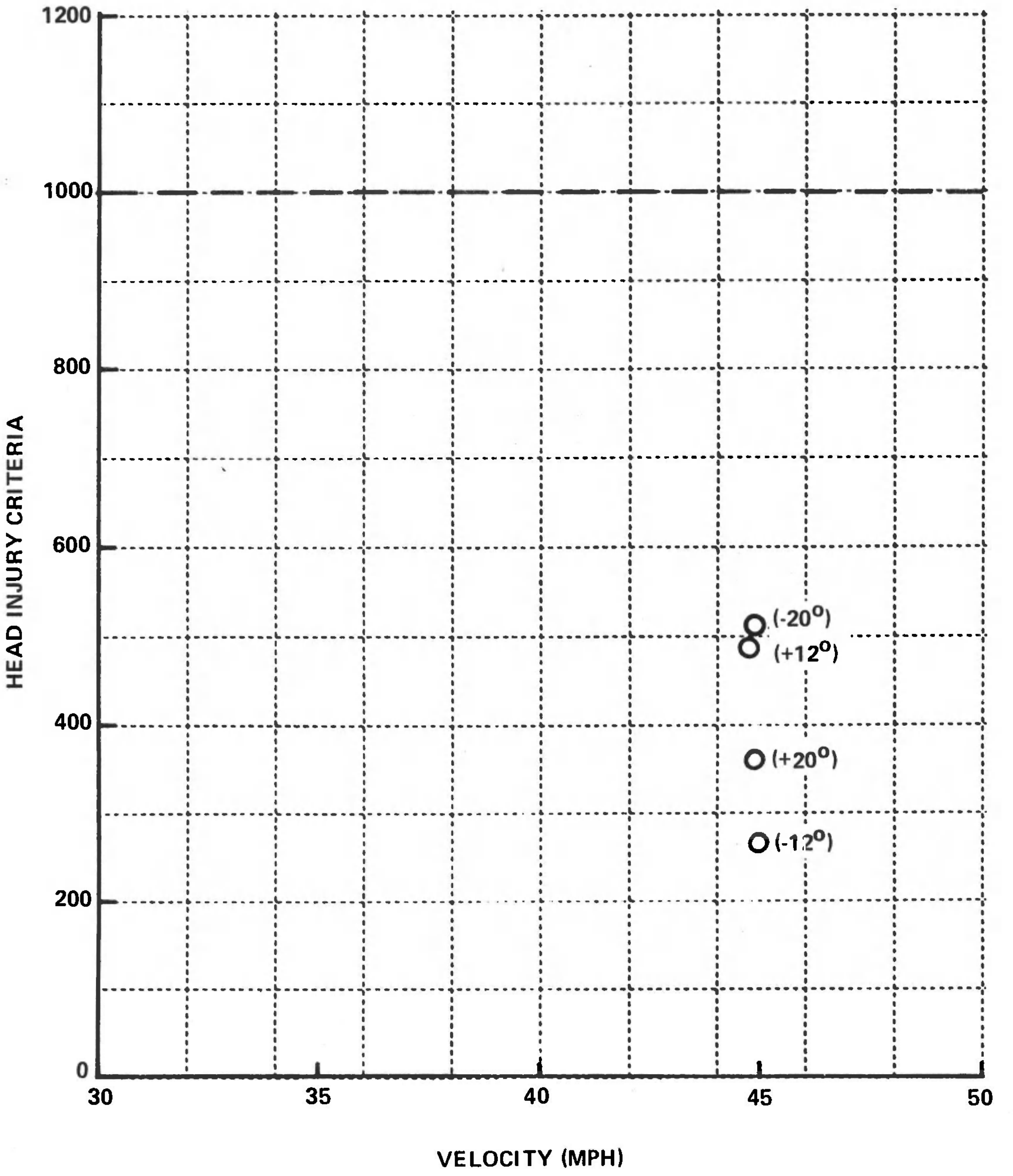


Figure 32 DRIVER AIRBELT VALIDATION ; ANGLED SLED TEST RESULTS (50th PERCENTILE MALE)

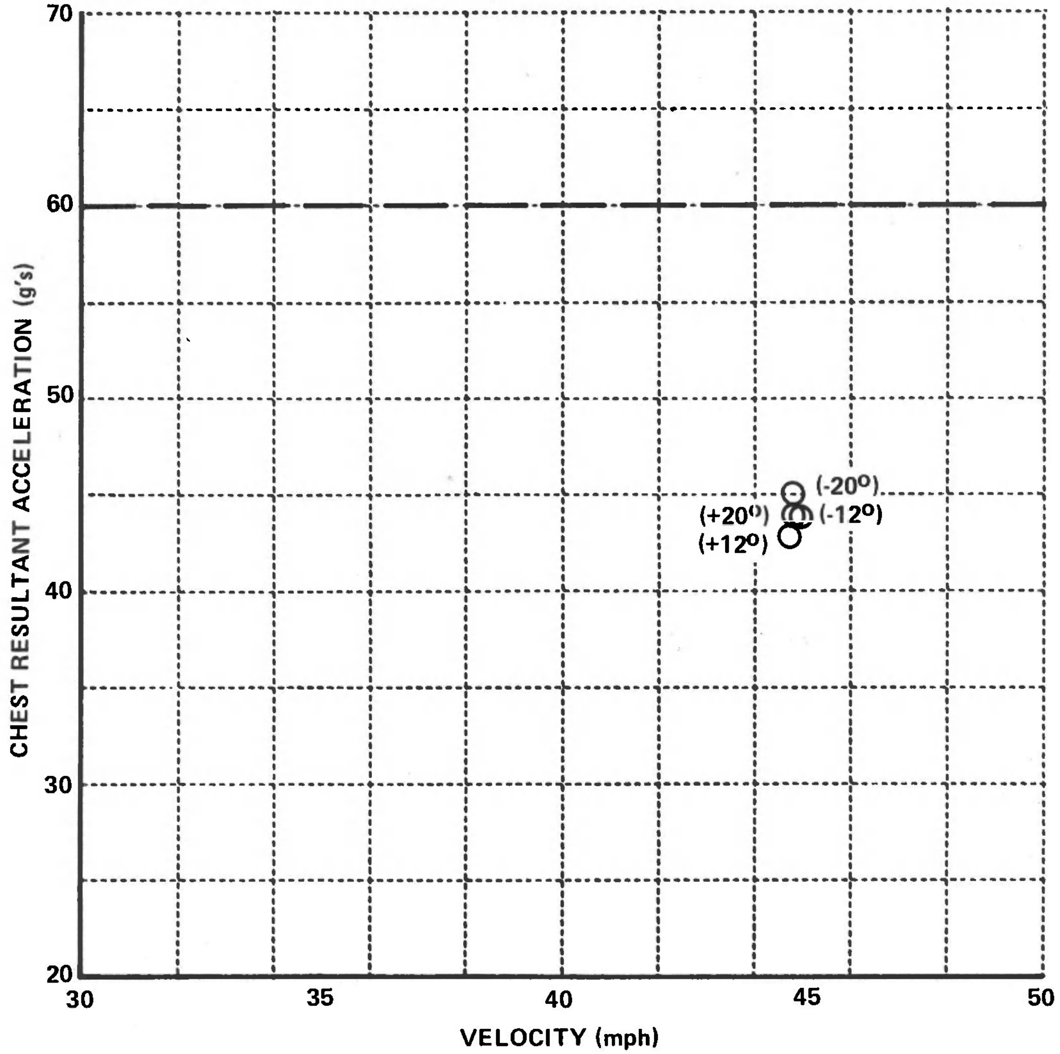


Figure 33 DRIVER AIRBELT VALIDATION; ANGLED SLED TEST RESULTS (50th PERCENTILE MALE)

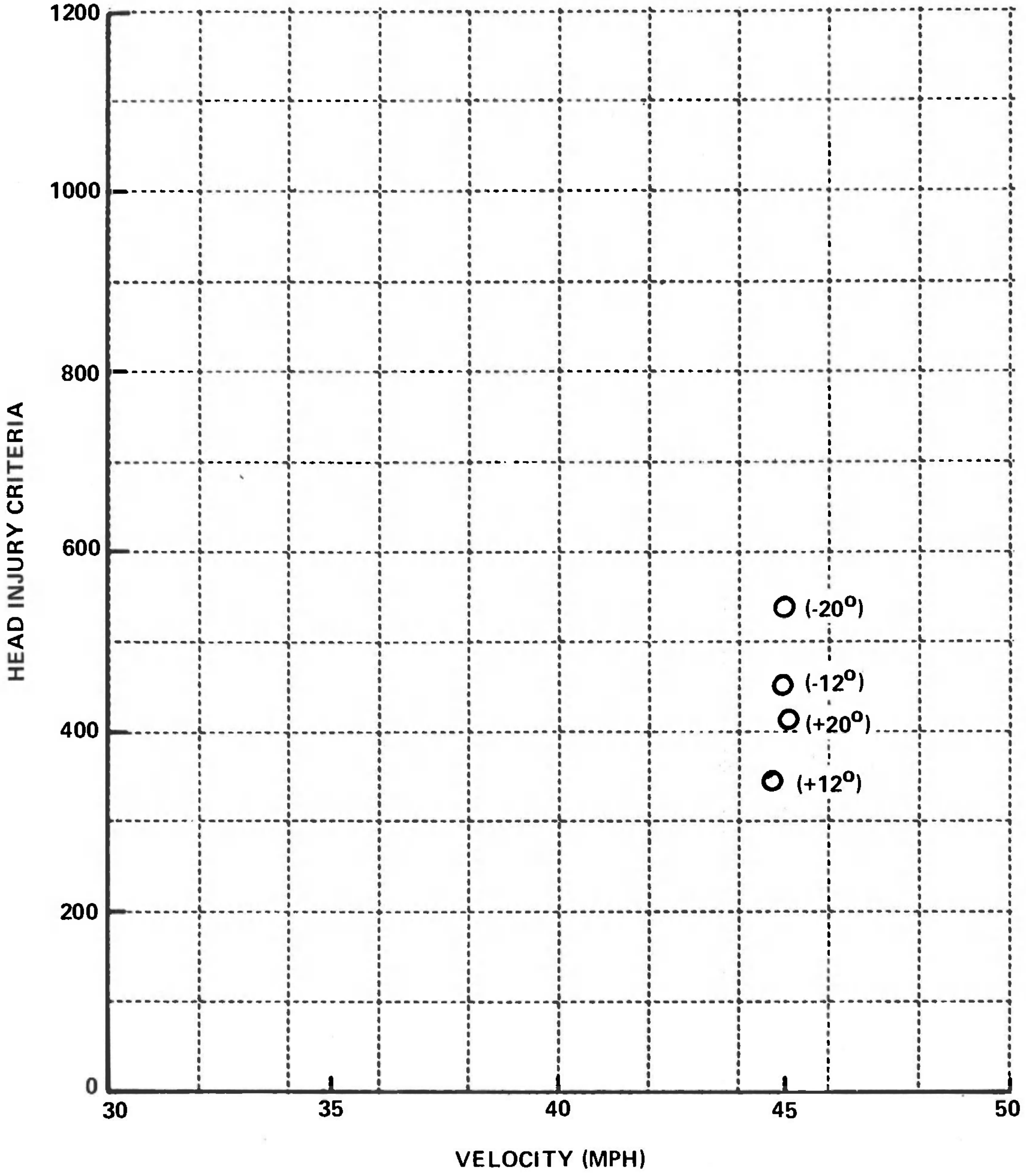


Figure 34 PASSENGER AIRBELT VALIDATION; ANGLED SLED TEST RESULTS (50th PERCENTILE MALE)

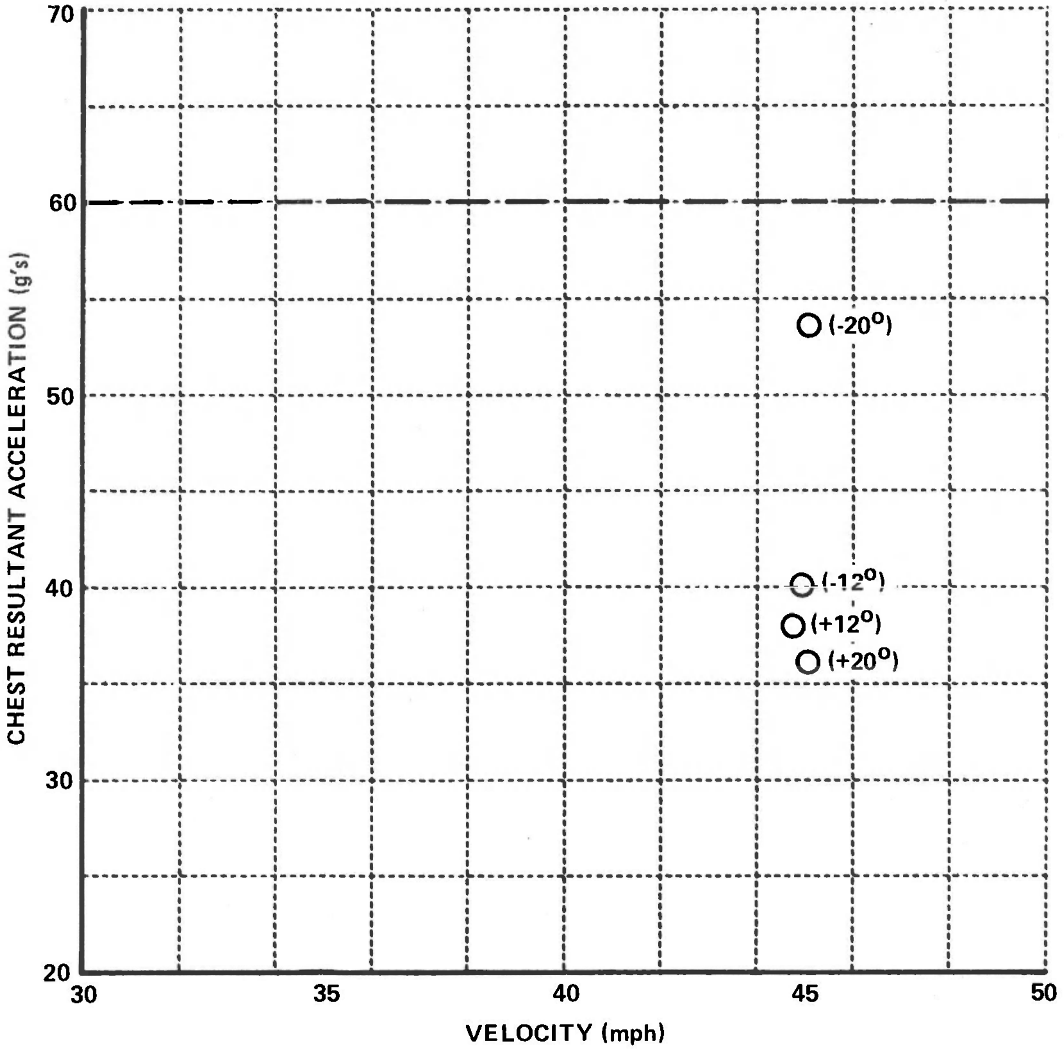


Figure 35 PASSENGER AIRBELT VALIDATION ; ANGLED SLED TEST RESULTS (50th PERCENTILE MALE)

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

(1) The major goal of the Phase III RSV air belt effort was accomplished. An integrated, producible restraint system was developed from a Phase II design concept.

(2) A critical exploration of the range of capability of the system has been made. Occupant size performance as a function of velocity as well as the off design conditions of lap belt use and seat position have been examined.

(3) For the baseline or normally positioned occupant, acceptable kinematics and occupant injury responses were obtained for both driver and passenger 50th percentile size dummies at 45 mph. This satisfactory performance was demonstrated for aligned (0°) as well as ±20° sled angles. This level of protection is consistent with the frontal crashworthiness level afforded by the RSV structure.

(4) Satisfactory performance was demonstrated through the 40 mph speed range for 95th percentile male size dummies in both the driver and passenger seating positions.

(5) Some specific areas where the system can be improved were defined by this evaluation process. In particular,

- acceptable performance was not demonstrated for the 5th percentile female at 35 mph
- excessive chest restraint for the 50th percentile male driver occurs in the off design full forward seat position at 45 mph
- poor kinematics due to the 50th percentile male passenger coming off the seat occurs in the off design full rear seat position at 45 mph

6.2 Recommendations

The major performance deficiency associated with the air belt restraint system are the poor results obtained with the 5th percentile occupant. (Similar problems would be expected for the six year old size child dummy.)

Based upon very limited test results for the 5th percentile dummy, it appears that a reduction in hip travel is necessary to achieve acceptable kinematics. Potential solutions are:

- Use of a structural seat pan to provide resistance to plowing (forward travel of the hips) by the occupant. The seat used in the VW passive belt Rabbit may be acceptable for this purpose.
- Reducing the clearance between the knees and the knee restraint (presently ~ 4 inches).

Chest accelerations should also be reduced. This could be accomplished by lowering the force level of the air belt load limiting Takata webbing to 1200-1500 pounds.

It is believed that a stiffer seat cushion would improve the performance of the 50th and 95th percentile occupant. Recall that problems were encountered with keeping the 50th percentile passenger on the seat in the full rear position tests.

Lowering the load limiting level of the Takata webbing, on the other hand, would probably reduce the upper speed performance level for the 50th and 95th percentile occupants.

It is suggested that additional effort be expended to investigate these alternatives and the ramifications these changes would have on the performance of the other occupant sizes.